Light Metals 2012 *Edited by: Carlos E. Suarez*
TMS (The Minerals, Metals & Materials Society), 2012

PREBAKE POTLINE RESTART AFTER POWER SUPPLY INTERRUPTION

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Keywords: Potline Restart, Cell Restart Methods, Clad Failure

Abstract

In early January 2011 the decision was taken to perform an emergency shutdown of the newly converted prebake potlines of Kubikenborg Aluminium AB (Kubal). This was due to power interruptions that resulted in bath shrinkage, which was followed by the onset of random anode failures in numerous cells when attempts were made to re-energize the potline.

The present paper covers the methods for restarting the potline. These methods were first considered and tested on one or two pots to evaluate the individual method, taking into consideration the availability of trained personnel; cell limitations and logistics; metal purity for existing customer supply commitments; environmental regulations; and speed of restart.

In addition, the paper will provide the criteria used to select the appropriate re-start procedure for different cell conditions and the results obtained by each of the methods used.

Introduction

Kubal was initially commissioned in 1942 and is the sole aluminium producer in Sweden. It has been expanded and converted to different technology types throughout the years and it currently consists of 3 potlines (See Table 1).

Table 1. Reduction technologies installed at Kubal

	Technology	kA	# of cells	Startup year
Plant 1	PFPB Kaiser P-86 side-by-side	155	56	1987
Line A	PFPB R-2007 end-to-end	160	120	2009
Line B	PFPB R-2007 end-to-end	160	122	2010

Lines A and B were recently converted from 115 kA VSS cells to PFPB technology that was mutually developed by Kubal engineers and external consultants. Later, when Kubal became a part of the UC RUSAL Organization, the technology was renamed to R-2007 Prebake Technology. Three new rectifier transformers were purchased in 2008 to increase the line current. The two potroom buildings remained the same from the Söderberg time, with forced potroom atmosphere ventilation driven by electric fans. A new Alstom dry scrubber was installed for both potrooms.

Both prebake cells use 16 anodes assemblies with a 4-pin spider. All of the anodes are imported.

By the end of 2010 Plant 1 and Line A were operated at full capacity, while Line B startup was ongoing with 113 cells in operation out of 122 installed.

Power Failure and Line B Disconnection

On December 23[rd] a major power failure occurred that caused a chain reaction of power interruptions. Later it was identified as being due to a ground failure of a newly installed 35 kV transformer supply cable. Line A lost the line current, the Line B current was reduced from 159 to 140 kA, and auxiliary power supply to the Gas Treatment Centre, potroom building roof ventilation and illumination, and pot controllers was fully lost. Forty minutes later, the current in the B line was reduced from 140 to 50 kA to reduce fluoride emissions and allow manual control of anode effects in a potroom atmosphere full of fumes with an outside temperature of $-24^{\circ}C$.

After five and a half hours some of the electrical problems were solved and it allowed for the energizing of the feeders to the gas treatment centre, activation of the cell pot controllers, and intermittent operation of the potroom roof ventilation system over the next four days. After one and one half days it was possible to bring the potroom A line current back to the nominal level of 160 kA. The repair of the damaged high-voltage cable for the B line rectifier (27) took 13 days in total, as there was not workforce or spare cables available during the Christmas-New Year's holiday breaks in Europe.

Low ambient air temperature in conjunction with long current downtime and loss of transformer 27 in Line B resulted in bath level shrinkage in both lines and the decision was made to halt anode setting for three days. Attempts to catch-up with the anode schedule resulted in delayed reduction to 36 hours, but massive anode change did not allow raising the average bath levels over 13 cm despite bath-melting. Bath shrinkage caused problems with anode performance, resulted in random anode failures (thermal shock, bimetal clad damages, anode burnoff from assembly, etc.)

In the first week of January four cells in Potroom B were cut out due to anode burnoffs or separation of the bimetal clad joints, resulting in the line being down for 5 hours out of 25 hours. As a consequence of the failure of these four cells the shutdown of Potroom B became unavoidable under the existing conditions and the line was shut down to reduce further damage to the anodes, assemblies, and cathodes. After the shutdown around 40% of the metal was tapped from these cells. Problems similar to Line B occurred also in Line A, and two cells were cut out due to similar problems.

Part of the reason for the decision to shut down Line B was that curtailing the line allowed Line A to be brought up to full current leading to its return to normal operation. Nobody was injured through the time of this incident.

Restart techniques consideration

Kubal has never done a prebake cell restart, so external resources such as RUSAL Engineering Centre and independent consultants were used to identify the most beneficial restart technique. As gas-fired burners were not available for the preheat four other different methods were considered.

Crash Start

The method is well known and successfully used by different smelters [1], and recently it was used at RUSAL-Volkhov for restart after power interruption. Liquid bath is poured into the cold cell cavity with the anodes in place, the cell is cut in line, and the bath resistance is used to generate heat for the cathode preheat. Assuming relative simplicity, this method was initially counted as the most preferable for the restart. But additional review of:

- rectifiers condition (low speed of line current increase),
- lack of any shunts to bypass line-current over the cell,
- anode assemblies bimetal clad condition (relatively high nominal current density - 31 A/cm^2, if increases over nominal values - high proven risk of clad destruction),
- anode size (1460*835*620 mm, 1.2 mt), with significant thermal shock tendency,

led to rejection of the method from the trial list to secure personnel safety and reduce potroom equipment damage.

Metal Restart

This technique is also world-wide known and often used in such cases when many cells have to be cut in line simultaneously to secure a certain rectifier voltage [2]. Initially, this method was tried in the two cells that were cut out in Line A.

To prepare the cells for restart the anodes were removed and the metal pads were cleaned using excavators and hydraulic hammers to remove the frozen bath back to the side ledge of the cathode cavity. The metal pad surface was vacuumed (in virtual shadow of the anodes) to secure reliable electrical contact. The pad topography was measured and documented. New anodes, or good quality butts with remaining lifetime of 60% or more, were clamped to anode beams, 20-30 mm from the metal pad surface. In cases of metal spikes or when non-extractable carbon pieces were higher than the overall metal surface, anodes were set 5-10 mm higher than these points, and the rest was set into the cell referring to the first one. Anodes were fenced with hardboard to secure clean ACD, and peripheral area was insulated with crushed bath material, securing the space for metal addition in the tapping hole area.

Liquid metal was added to the cell to secure electrical connection; the target anode immersion into the metal was set at 60-70 mm (between 3.5 and 6 mt of metal to add). After metal addition, the cell was cut in line at full current and the reheat process started. During the trials, as metal was added, inter-anode seams were insulated with fine crushed bath to prevent anode airburn and improve heat generation. However, after 12 cells were restarted in Line B it was decided to cancel this type of insulation, as 20 mm thick crushed bath walls, sliding down along the side anode surfaces, created major difficulties for liquid bath distribution in ACD during bath start. Insulation was changed to 50 mm thick rockwool, placed on top of the anodes and the peripheral area of the cell. Changed procedure also improved heat transfer from warm anodes to cold ones through IR radiation. As metal added in cell freezes up in 15-30 minutes, for the first 24 hours on preheat anode beam or individual anode height adjustment was forbidden to avoid equipment and anode assemblies' damage. Then the voltage of the cells was gradually increased having 2.8 V as a minimum target. The anode current distribution was checked every two hours, and anodes taking over 20 kA were temporarily disconnected to even up the current distribution. The cathode current distribution was not checked. Anodes were also visually checked for airburn - sides, tops and nipple holes, and the temperature of the anodes was evened out by rockwool insulation repositioning. In case of significant nipple hole airburn, or burnoff, such anodes were changed to hot butts available from operating cells. During the trial period, two anodes out of 32 were lost for these reasons. The lowest target metal temperature for bath start was detected at 780 °C, as a lower temperature did not provide a reliable and safe bath start. Usual preheat time was 90-100 hours.

The regular tapping vehicles were used to transfer 8 tonnes of liquid bath into the startup cell. If necessary, more bath was delivered with bath transferring forklifts. Special wooden shields for startup crew and pot controller protection were used, as during startup the cell could become very unstable, creating metal splashes. The startup crew was wearing aluminized cloths and face shields. As bath was added in sufficient quantities, startup anode usually was provoked. The target anode effect voltage, depending on cell condition, was 18 V and below to avoid sodium production from the bath. As bath temperature reached 980-990°C, the AE was extinguished, bath and metal samples were taken and 300 kg of soda were added to compensate for cryolite destruction during the startup anode effect.

Graphite Bed On Metal Pad Restart

The method has been successfully tried in one cell. It can be even called "semi-crash start", since the aim of the method is to preheat anodes up to 600-700°C (to avoid thermal shock of big anodes), but leave metal pad mostly solid, then add bath and start the cell. Metal pad was cleaned from remaining bath and burn-off anode pieces and flattened out by casting additional metal into the cell. Graphite stripes were formed (two under each anode), anodes were set on top of the stripes, covered with insulation material and fixed to the anode beam with start-up clamps, and the peripheral area was insulated with bath material. Then cell was cut in line. In the first 8 hours the anode current distribution was checked hourly, and anodes drawing too high load were insulated for 1-2 hours. Two anodes out of 16 cracked and had to be changed. After an initial period the cell voltage and anode current distribution stabilized. The anode current distribution was checked every two hours and the preheat continued for total 50 hours, giving final anode temperatures in the range of 600-650 °C evenly spread among the 16 anodes. The startup clamps were replaced with regular clamps, and 12 mt of liquid bath was added to stabilize the cell voltage in range 15-18 V. Overall, the start went smoothly without metal splashes or cracked anodes.

However, attempts to try the method on industrial scale gave approximately 25% success. There is an ultimate requirement to good electrical contact and remaining metal pad flatness. In case of uneven metal pad surface or poor metal pad – bottom block contact cell voltage control becomes impossible, and uneven current distribution drives to anode thermal shock. In such cases metal was poured into the restarting cell to secure good electrical connection, thus converting the method to metal restart.

Resistor-Bake Restart

This well known method [3] has not been tested due to in-house experience availability, but was used for cells with high remaining metal pads and not enough volume to add sufficient amount of bath for the restart.

The metal pad was removed using overhead cranes and front-end loaders, and then cell was restarted using the normal resistor bake procedure. This technique secures quick start up pace with minor labour intensity and anode loss. But as it was observed, metal pad extraction originates shallow cracks, starting from the area of initial metal pad lift-up and going down at a small angle into the bottom blocks. 30% of the cells with extracted metal pads had visible cracks. Therefore the technique was used only in case when any of the other restart techniques could not be used.

Finally, the metal preheat method was used as basis, with graphite bed and resistor-bake as optional for cases of low and flat metal pads and high uneven metal pads, respectively.

Start-Up Preparation

Due to the emergency conditions of Line B shutdown significant damage to anode assemblies occurred. Initial estimation of 25% assemblies to repair ended up at 47% from overall assembly park. To secure restart and reliable operation the repair capacities were increased by 6 times by adding extra shifts and hiring additional contractors, but even though the availability of assemblies (and rodded anodes respectively) was a concern, which limited the restart pace at several points.

Butts removed from shutdown cells were sorted. A special daytime crew was formed to clean the covering material from the spent anodes and assemblies. Recycled bath material then was processed through existing facilities and used for covering of restarted cells. As butts were to be sold, old Söderberg pin blaster was commissioned back into operation to allow final cleaning of high butts, which could not fit the existing spent anode cleaning equipment. Butts of acceptable quality and with the remaining lifetime of 60% or more were reused without cleaning in Line A and for preheat and startup in Line B.

A special maintenance crew was formed to be responsible for cell superstructures equipment revision, cathode cleaning and shunts placement.
The rectifiers' lowest voltage limit was not a concern for the start of the process as the possibility for busbar connection exists between Line A and Line B. While Line A was running from the Line B rectifier station, extra maintenance of Line A's oldest rectifiers, produced in 1962, had been performed.

As preparatory work was done in the first two groups (40 cells), the 20 first cells were dressed with anodes and bath material, and restart of the potline was initiated.

Pot Line Startup

Schedule

Quickest possible restart was the target; however, several constraints mentioned in [2] were discussed:

- Iron content in disconnected metal pad cells was above 0.6% (assemblies damage), while the cast house product mix has a maximum iron content of 0.18%. Startup rate of 2-3 cells per day only would satisfy the cast house needs, as there was virtually no spare capacity to cast high-iron metal.
- There were 4 tapping trucks, while two in 24 hours operation were necessary to perform tapping for Line A and 1. As restart of Line B continues, the availability of tapping tracks for bath transferring becomes less.
- Startup drive to anode excessive airburn, resulting in higher rate of anode consumption. Startup front could leave behind a number of anodes to be changed for airburn or scheduling reason for up to 140% compared to regular schedule even at maximum productivity.
- Two anode covering vehicles were available, one for each of Lines A and B. Every cell after restart requires in first day 16 times more covering material and time than regular. Extra anode changes also require additional time to cover.

It was resolved that two cells per day schedule was the most feasible for current Kubal circumstances.

Organizational Aspects

Dedicated Preheat and Start-up team was necessary for the restart. Fifteen experienced blue-collars from Russian RUSAL operations were invited to take care of the metal restart, anode adjustments, voltage control and bath addition functions. A basic course of the Swedish language was conducted; however, for safety reason, the team work was 24 hours covered by an interpreter service.

Twelve shift Kubal employees formed a team of Start-Up and After Start-Up support, responsible for the initiation of the anode changing schedule, bath melting in the cell and troubleshooting if that occurs. Once the cells got stable (after 3-4 days of operation), regular shift personnel took control. Both start-up teams were situated in a special control room and were lead by the start-up superintendent.

A team of four daytime employees was dressing the cells with anodes, bath material and rockwool according to the selected technique 20 cells ahead of start-up front. Bath addition with tapping tracks additional bath transferring and metal tapping was done by regular shift personnel upon the start-up crew's request.

Kubal does not have in-house anode production, so the intention is to consume the anodes to their minimum possible thickness. As the startup was progressing, significant amounts of butts were generated, which have to be reused. Teams of two employees lead by a process engineer worked daytime 7 days a week to sort out, mark and schedule butts reuse in the process.

Actual Restart

On February 21st the first 20 cells were energized, where only two were cut in for metal preheat. Restart of the first 20 cells targeted to personnel education and to identify the maximum feasible amount of cells kept on preheat at the same time. Through experience it was determined that with existing headcount it is feasible to preheat no more than 15 cells simultaneously. Less than 6-8 cells cut in for preheat slows down the start-up; while more than 15 cells create problems with the workforce and startup equipment availability, logistics and, in the end, safety. Thus, the initial schedule with bath start of 2 cells a day has every day undergone the review depending on number of cells on preheat, situation with started cells, and location of cells on preheat in potroom.

Lack of any gas preheating equipment resulted in a special procedure, when the metal in the cells scheduled for preheat was added in 2 steps. First step addition usually amounted to 500-600 kg to evaporate potential humid and frost from metal pad rat-holes. In 10-15 minutes the main portion of metal was added to secure anode immersion into the metal at 60-70 mm.

Because of the special bus-bar arrangement the cells were energized by groups of 20 (10 on upstream and downstream sides), where 5 cells were cut-in for metal preheat, and remaining 15 were shunted to form the electrical circuit. As the preheat of cells advanced, more cells in the groups were cut in for preheat by shunt removal, also in sets of 5. Potline busbars split was done after 40 cells were restarted and Line B voltage exceeded 150 V.

As the restart progressed, around 50% of the cells were tapped for metal prior to bath start, as metal temperature reached 710-730 ^{0}C. The tapping amount was in the range of 0.5-5 mt. This allowed to improve the preheat time, as well as cell stability and personnel safety during bath start.

Stabilization of Potline Operation

Restarted cells were used as bath cells until the startup front was moved into the next 20-cell section. Therefore cells were covered with pure crushed bath to save heat and produce bath. The tops of the anodes were covered a day later with recycled crushed bath. After bath melting is finished, the covering procedure was back to normal.

Usually the Start-up team switched alumina feeding on with rare intervals. Then the After Start-Up team allowed 3-4 anode effects on restarted cells to secure that bottom muck is getting dissolved, and after that they switched automatic feeding control on.

The metal height was usually excessive after start-up, and cells were running relatively cold after the restart. Depending on iron content the target value was usually reached in 1-2 days.

The regular anode changing cycle is 30 days, however, for the startup groups it was kept at 25 days for the first month, as airburnt anodes were consumed faster. Every new cycle improved the anode condition, so the changing cycle was brought back to 30 days in 3 anode changing cycle, or 75-85 days.

Restarted cells required higher than regular voltage (see Figure 1) for several reasons:

- Small anode cross-sectional areas caused by airburn during preheat
- Low contact surface in the nipple holes (50-75% from regular) caused by airburn
- Presence of muck at the cathode bottom after emergency disconnection
- Cold condition during metal preheat
- Additional anode change due to shorter cycle (airburn) or anode burnoff.

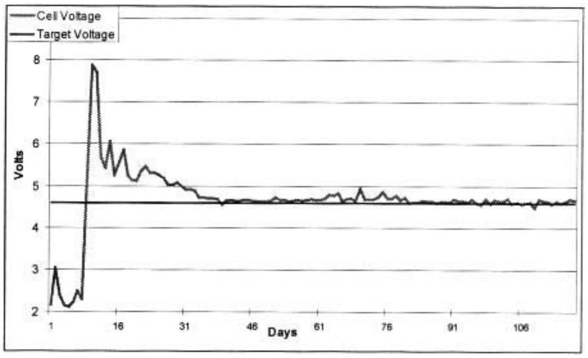

Figure 1: Typical metal restarted cell voltage development

The cell voltage followed the anodes improvement and reached the target in 75-85 days.

The bath chemistry control aim was to bring the amount of AlF_3 excess from 6-7% after restart to the 10.5% target value within 30-45 days, depending on cell performance and condition.

Results

Schedule

The potline was restarted in 100 days despite being scheduled for 72 days. In addition to the cast house limits on metal purity, the restart process was faced with other challenges:

- Insufficient amount of rodded anodes due to lack of repaired assemblies, which delayed the startup after putting 80 and 100 cells back into operation.
- Environmental issues, as F emissions due to restart went up to 0.8-0.9 kg/mt of Al produced. This was over the limit of 0.6 kg/mt, and the authorities demanded to stabilize it.
- As expected in [3] and discussed above, logistics problems and lack of machinery to support both operations and restart in the end of restart process, when the number of cells in operation in Line B exceeded 100 (90% capacity utilization and higher).

Potline performance

As can be seen from Figures 2 and 3, there is no traceable change in cathode performance, i.e., the noise level and cathode voltage drop.

Data shows that in three months after the restart Line B is back to normal voltage, current efficiency exceeds 95%, and anode consumption is in the same range as for Line A.

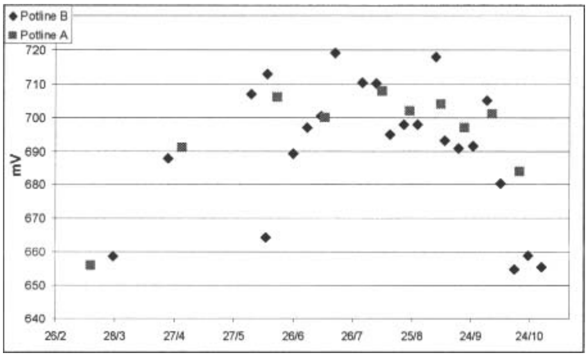

Figure 2: Cathode voltage drop for Potlines A and B

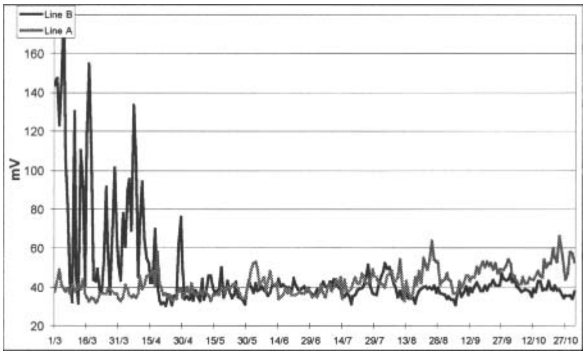

Figure 3: Noise level development

Cell Life Prediction

Two cells were lost during the restart, after 5 and 7 days from the bath start point. Two types of cathode blocks were used for the Line B construction, extruded and vibroformed, and both failures occurred with extruded blocks, while vibroformed blocks showed signs of minor lamination on 7 cells without fatal failures. Autopsy of one failed cell concluded the root cause was uneven anode and, therefore, cathode current distribution. However, no extreme deviations from the "standard" anode current distribution pattern (recorded for other successfully restarted cells) were noticed. Thus, one of amendments to autopsy could be that extruded block properties are not fully suitable for metal restart conditions at R-2007 cells, as there are no remarks on extruded blocks performance under regular conditions.

Cell life prediction was done, using the Weibull method [4, 5]. The life of Line A cells, which have identical to Line B lining design, but not undergone emergency disconnection and restart, was predicted at 2330 days, while for restarted Line B it was 2570 days. Since only two failures occurred, the accuracy of Line B cell life prediction can be questioned. However, existing tendency shows that the metal restart technique allows to save the majority of cell life despite the emergency conditions where cells disconnection was performed.

Experience

The Kubal team for the first time faced an emergency shutdown and then a prebake cells restart process. Teamwork of operators, process engineers, supervisors and Russian Start-Up Team brought to Kubal an invaluable experience in process control, cell troubleshooting and managerial aspects. After the restart this resulted in noticeable safety, operational and economical performance improvement in both A and B potlines.

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