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SIMULTANEOUS PREHEATING AND FAST RESTART OF 50 ALUMINIUM REDUCTION CELLS IN AN IDLED POTLINE

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A new soft restart technique for a potline

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Abstract

Due to the global economical crisis a significant amount of primary aluminium production capacity has been shutdown. A number of different strategies to restart idled aluminium reduction cells have been discussed in the literature [1, 2]. This paper describes the successful development and execution of the start-up of 50 cells simultaneously in one potline. The procedure is based on restarting reduction cells using a cold metal plate. Contrary to electrical preheating of new cells with use of cokes or graphite, these cells have been prepared with anodes positioned in direct contact and on top of the cold metal plate. The rate of preheating of the cells and associated melting of metal is controlled by a gradual line current increase. The actual start-up of the cells is performed sequentially by the addition of liquid electrolyte and moving the anode beam upwards. In this respect 50 cells have been preheated and restarted in 8 days.

Introduction

A complete shut down and restart of a large number of cells is not a practice that a smelter carries out regularly, because of the time consuming characteristics and additional costs involved. At Aldel, the last shutdown and start-up was after a fire in the transformer building in 1977. However, due to the economical circumstances, Aldel has decreased its annual production capacity by 40% with the closure of Potline 1 in 2009.

This capacity was partly taken into operation again by June 2010. Generally a pre-heat and start-up of a whole potline is carried out cell by cell. However, this is not possible at Aldel due to the configuration of the rectifiers. The rectifiers require a minimum voltage of 110 V, which is equivalent to 24 cells running at 142 kA. Since this is not achievable instantaneously, a new method was developed to restart one cell at a time while maintaining the total line voltage above the required level.

During the design and development phase of the restart method, it was clear that preheating a large number of cells simultaneously offered the best option in terms of maintaining the required voltage and associated stability of the line current. In contrast to cold crash starts this method provides a soft and fast sequential start-up of a large number of cells (50 cells in this case).

In order to develop a dedicated start-up procedure a number of industrial experiments were carried out in the remaining operating potline. In addition to the minimum required voltage, the current distribution within the cathode collector bars is of main concern. The tests confirmed that a 'gradual amperage increase' start-up was possible and that the required minimum line voltage and a controlled current distribution within the cathode bars could be achieved. The main focus of the start-up procedure is keeping the line voltage high enough to prevent the rectifiers from increasing the amperage above safe operating levels.

Several methods for preheating were tested. Although these methods demonstrate more or less the same outcome in respect to the voltage characteristics per cell, the cathode current distribution between the individual collector bars shows large variations. The anode current distribution was identically sensitive to the rate at which the amperage was increased over time.

Restart restrictions

For the restart of Potline 1 a number of restrictions were identified that determine the characteristics of the new method. Prior to the shutdown these restrictions and associated actions were clarified.

Cell conservation

The shutdown procedure was linked to the condition of each cell in order to be prepared for preheat and restart. Cells that were not considered for restart were completely drained of metal. Cells that were suitable for the new preheating and restart method were preserved with a metal pad layer of 10 cm. This was undertaken to protect the cathode surface during the shutdown period, provide a flat and conductive base for positioning the anodes during preheat, and to protect the surface during liquid bath mass transfer (slow down the rate of increase of the cathode temperature).

Rectifiers

Potline 1 has five rectifiers with a capacity of 40 kA each. Four of these rectifiers were built by Siemens in 1965. The minimum voltage of these rectifiers in the lower voltage range is 110 V. If the voltage falls below this voltage, the rectifiers automatically compensate by increasing the amperage. In 2006 a new rectifier ("E11") was added to the potline in order to secure N-1 operation and to increase the line current. This rectifier operates in the range of 0-370 V.

Bath transfer

The liquid bath transfer during start-up of the first cells must be done from Potline 2. If cells are preheated simultaneously, the rate of bath supply is obviously higher than in a normal cell by cell restart. Also, the rate of bath production after start-up is much higher because of the smooth and complete preheating of the cells. With this bath production, the bath levels can increase fast creating the cells with high iron. In this respect the logistics and management of the bath transfers are of critical importance.

Testing

In preparation of the start-up of Potline l, a number of preheating methods were developed and tested. These investigations were conducted in Potline 2 and were focused on the identification of potential constraints in respect to the preheating and start-up. A method was developed using a predefined metal thickness and a flat metal pad to ensure good electrical contact between the anode and the metal plate. An average resistance curve for a cell was determined, which was used as the basis for the ramp-up of the line amperage and the start-up of the cells in Potline 1.

At Aldel, two independent mechanisms according the overall line voltage development are important. These mechanisms are related to the preheating curve defined by the gradual stabilization of the anode and cathode current distributions, and the voltage behavior of a cell after liquid bath addition. Both mechanisms determine the balance between the rate of decrease in the overall line voltage due to preheating and the increase in the voltage due to sequential start-ups.

Test set-up of cell

During the shutdown of Potline 1, a strong emphasis was put on the conservation of the cell condition. However, it was found that the surface of the remaining metal pad was still not smooth enough to ensure good electrical contact. Therefore the cathode surface had to be flattened out by casting additional metal into the cell. Figure 1 shows the flattened surface with a number of anodes positioned on the surface in Potline 1.

Figure 1: Preparation of the metal surface in Potline 1.

The anodes were put on top of the flattened metal surface and surrounded by hardboard. Coarse grain crushed bath material was poured between the hardboard and the remaining side ledge to protect and build new side ledge during the start-up phase, and to generate additional bath material for the start-up of other cells. On top of the anodes a thick layer of insulation material and bath material was positioned to prevent anode airburn completely (given that the preheat period would extend for a number of days) and also to generate extra bath material. Figure 2 shows the set-up of a cell in Potline 2. The amount of bath material for covering cells in Potline 1 was increased in such a way that the insulation layer was not visible.

Figure 2: Test setup of cell in Potline 2

Preheat curve

Before the start-up of Potline 1 it was very important to get a clear indication of the voltage development related to the actual current and ramp-up rate. First of all, the cells needed enough voltage to generate 110 V across the line, for stability of the line amperage at a controlled target. Secondly, it was important to understand the characteristics of the voltage development during the preheating phase. Experiments showed a fast decline in the voltage during preheating. The rate of decline depends critically on the rate of line current increase, the actual current and the initial current distribution in the cathode bars. The latter itself dependents on the rate of current ramp-up - a more even current distribution is obtained when the current is ramped up more slowly over days.

Because the experiments were carried out in a running potline, the period of the ramp-up was limited to 2 hours. It was found that several connections between the cathode bars and bus bars were lost as a consequence of rapid current increase. Due to the end-to-end configuration of the potline most of the current enters and leaves the cell at the ends. However, it was not possible to predict the specific cathode bars causing most of the problems. In some cases a particular collector bar drew 50% of the total current during the ramp-up. It was found that hot cathode bars remain consistently above a line current of 40 kA. These bars had to be controlled with additional cooling above 80 kA. This phenomenon is probably due to the expansion of the cast iron in the cathode block during preheating.

Figure 3 shows the preheating curve of a cell tested in Potline 2. Initially the resistance is high - equivalent to 6 V at 120 kA. During the current increase one of the cathode bars disconnected from the cell. After approximately 9 hours at full current, the voltage drops gradually to 3 V. The cell stays at this level for 2 days. The temperature in this period is equally distributed and increased in the cell. The metal reaches an average temperature of approximate 400°C before the voltage decreases to 1.5 V. At this point, the metal is liquid, after which the cell can be started.

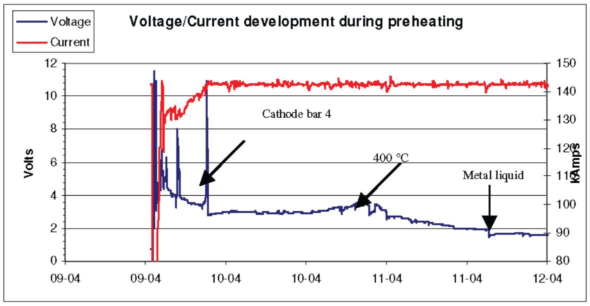

Figure 3: Voltage and current development during preheating

Cathode and anode control at current ramp-up

After 4 to 5 hours at 142 kA the anode current distribution became important. The need for inspecting the cathode current distribution was at that point not critical anymore, since it stabilizes very fast after exceeding 90 kA. Anodes that draw too much current were isolated from the anode beam and after a while reconnected again. An anode that did not draw any current was pushed onto the metal plate. Usually these anodes draw current again.

During the test it became evident that preventing the anodes from heavy airburn is essential. Otherwise anodes were burned off after 3 days requiring the immediate start-up of the cell. With use of good protection against airburn of the anodes, the preheating time could be extended to at least 7 days which allows gradual heat-up of the full complement of the potline.

Start-up curve

As Figure 3 shows, the voltage decreases after a certain period of time. In order to keep the line voltage above the required level the cells have to be started. The start-up curve determines the actual speed in which cells should be started sequentially to keep the line voltage above 110 V in respect to the start-up of Potline 1. Figure 4 shows the start-up curve of a test cell in Potline 2.

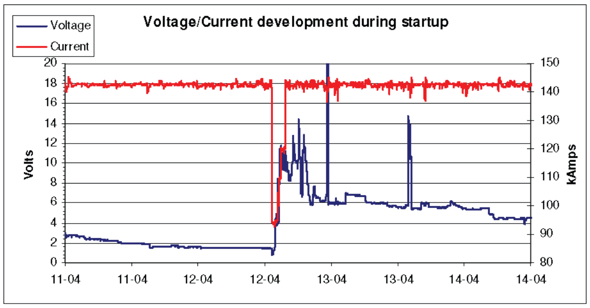

Figure 4: Voltage development during start up

Notice that the current in Figure 4 is decreased to 95 kA before the cell was restarted. During the start-up a number of anodes were disconnected from the beam (clad failures) and had to be replaced during the restart. The last two voltage peaks in the graph are anode effects and related to switching on the alumina feeding.

Start-up Preparation

The main focus of the preparation for the start-up of Potline 1 was to achieve the following objectives:

- Number of cells required (>110 V)
- Bath flow logistics
- Control of the ramp-up rate
- Organizational aspects of start-up
- Minimize interference with standard potline operation

Number of cells

The number of cells required for the start-up of Potline 1 were calculated based on the minimum voltage of 110 V. 84 cells were taken into the circuit of which 34 cells were short circuited. These cells have a voltage drop of 0.7 V at 142 kA. Based on the results of the tests 40 cells were required for the metal bake re-start. In order to provide maximum flexibility 10 additional cells were taken into the circuit during the final execution of the restart of Potline 1. Another 10 cells were prepared with anodes on top of the metal, but were not in circuit. These cells could be taken into the circuit if the voltage would fall below the required 110V.

Bath flow logistics

The availability of liquid bath was one of the major items prior to the start-up, because of the large number of cells that had to be started in a short period of time. In addition, the risk of iron contamination in Potline 2 is considered to be high. To minimize the number of cells for bath production, crushed bath material was used on top of the insulation layer as described earlier. Also, for safety reasons (to avoid transport of liquid bath over long distances) the procedure developed for Potline 1 focuses on its own liquid bath production as soon as possible.

Control of the ramp-up rate

It was clear that in the initial phase of the preheating procedure, attention should be paid to the cathode current distribution of 50 cells simultaneously and therefore the ramp-up of the current should be done in a controlled manner. This prevents one or more cathode collector bars or anodes drawing too much current and consequently failing. There are only two mechanisms that can be used to prevent the break down of cathode collector flexes. These are using air lances and stop ramping up the current. Since there were no cells running in Potline 1, the current could be ramped-up very slowly, which minimized large instabilities in the cathode current distribution by providing enough time for the cathode collector bars to thermally equilibrate. The time needed for ramping up the current is limited by the airburn of anodes, but also in the decline of the total line voltage as a consequence of stabilizing cathode bars.

Organizational aspects of start-up

It became clear that there was a need for a highly trained and specialized start-up team for the start-up of Potline 1. This start-up team consists of a number of operators, a start-up leader and a process control person. For the start-up team a dedicated control room was set up to manage the complete information flow. Each cell’s status is visualized on a whiteboard.

During the gradual ramp-up of the line current in Potline 1 all resources available were focused on measurements of the anode and cathode current distributions. Based on these measurements the current is ramped up or actions are taken to prevent potential problems at either the cathode or anode side.

After the current reaches a certain level the cells are started. From that moment on for each shift, two teams are needed to control the preheating, cell start-up and taking cells in normal operation. The first team is the start-up team led by the start-up leader. This team is responsible for the preparation and the execution of the start-up. The second team is responsible for measurements and corrections on the remaining cells under preheating condition. Secondly, this team guides the started cells to their normal mass and energy balance (bath temperature and composition, operating voltage and metal depth). The second team was led by the process control person.

Minimize interference with standard potline operation

A start-up of this scope will have its impact on the performance of the other Potline 2. To minimize the interference on the operations of this line, a start-up plan was developed for the actual start-up sequence according to the geographical location of the cells in the potline. Also, the transfer of normal cells to standard operation is taken into account.

Actual execution of start-up Potline1

Ramping up current

At June 9th 2010, rectifier E11 was activated and the current was ramped up very slowly to 40 kA. After that, the other rectifiers were activated and the current was increased to 120 kA. The plan was to increase the current by 5 kA per half hour. In practice the aim was to keep time flexible to give all cells sufficient time to normalize the cathode and anode current distributions.

Figure 5 shows the development of the overall line voltage and current during the ramp-up. The green line represents the minimal required voltage.

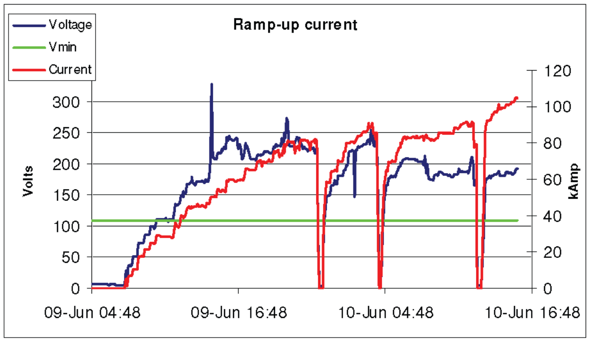

Figure 5: Voltage and amperage development during the ramp-up

Figure 5 demonstrates three current outages. These outages were related to anode clad failures in three cells in the preheat state during the ramp-up. However, these cells were not lost and they could be started later using the cold crash start method. After cutting the power, the current had to be ramped up smoothly to the previous level.

The cathode and anode current distributions were measured every 2 hours. The measurements below 40 kA were all indicative, since the noise during the initial ramp-up was extremely high. Above 40 kA the cathode and anode current distribution measurements were reliable and repeatable. The target current within the collector bars was set to a maximum of 10 kA. Also, the current per anode was limited to 10 kA.

Anodes, which did not draw any current, were reconnected to ensure a better contact with the cathode surface. If anodes draw too much current, the anodes were isolated from the beam. After two hours the anodes were put back in circuit again.

A critical phase was reached at approximately 80 kA. As shown in Figure 5 three cells were disconnected from the preheating state. These cells became very noisy in the anode and cathode currents. The actual line current was monitored constantly. At 80 kA, it was decided to stabilize for 16 hours to redistribute the anode and cathode currents. Thereafter the current was gradually increased. No problems with the cathode current distribution were found above 90 kA and the main focus shifted towards the control of the anode current distribution. After the metal was liquefied with the anode positioned in the metal, the problems regarding the anode current distribution were gone.

The actual line current was monitored constantly. It was found that an increased instability in the current signal could be used to predict noisy and unstable cells. This method worked very well at Aldel and the number of cells that had to be cut-off was limited to the three mentioned above.

Starting up cells

Although the metal plate was not fully liquefied after reaching 120 kA, the cells were found eligible for start-up. The reason for starting these cells was a high level of noise and the risk of losing anodes due to too high current. After the first cells were started, 2-3 cells per shift were started. Finally, Aldel was able to preheat 50 and start-up 47 cells in 8 days.

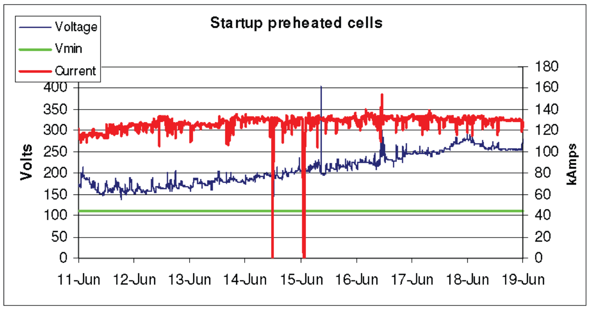

Figure 6: Start-up of preheating cells

Figure 6 shows the overall line voltage and current development during start-up of Potline 1. There are two current outages during the start-up phase. These outages are due to switching the rectifiers to the high voltage range. The line current was gradually increased to 130 kA during the sequential start-up of the cells.

Starting a cell

Figure 7 shows the start-up voltage curve of Cell 1035. It was the first cell started via the new procedure at Aldel. The metal plate is visible liquefied after two days of preheating on full line power. The cathode side of the cells reaches a temperature of 400°C.

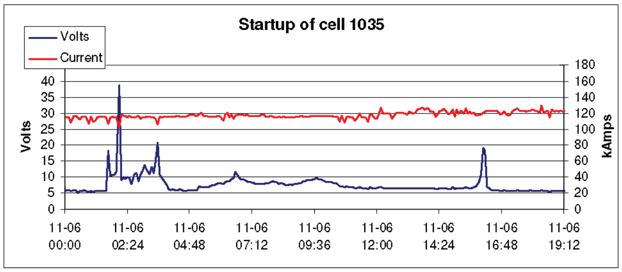

Figure 7: Start-up curvature of an individual cell

The start-up was executed as follows. Under full power, three to four ladles of liquid bath were poured into the cell as shown in Figure 8. After the beam was moved upwards, bath levels went down very fast as anodes went up. The beam was moved up until the voltage went up very fast to approximately 40-50 V. After that the beam was lowered until the cell voltage was stable at 20-35 V. In order to prevent metal and bath mixing, liquid bath was poured in very slowly.

Figure 8: Liquid bath addition to cell 1035

Due to the fact that the metal was not fully liquid by the first cells the bath temperature had to be controlled very well. As shown in Figure 7 the voltage was increased several times to melt the metal. After a few days, when the metal pad was liquid, the control of the bath temperature was easier (Figure 9).

Guiding a cell to normal operation

Initially the temperature is low and therefore the initial voltage should be high or soda ash should be added. A total of 7 MT of soda ash was used during the start-up of the 50 cells. The voltage should remain on a high level to melt the metal completely. If the voltage remains too high for too long, the temperature will reach critical levels. This can cause tap-outs. Sometimes it was not possible to lower the voltage in case of high temperature due to the large amount of generated bath material by the cell.

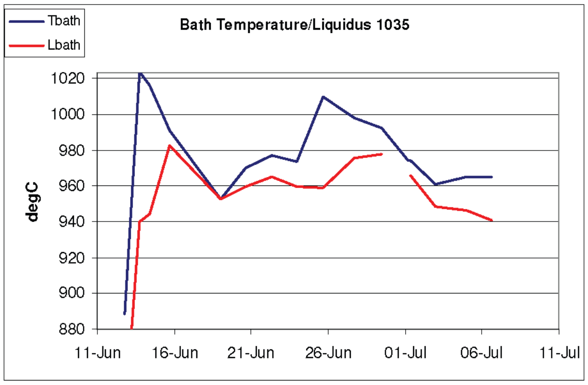

Figure 9: Temperature and liquidus development of a typical cell.

The voltage is kept high to melt the metal. In this respect the rate of melting of metal is important. After the metal melts the voltage drops very fast and the voltage needs to be controlled. When the metal was complete liquid the metal set-point of the cell is determined and the cell was ready producing metal for the cast-house after taken metal analysis.

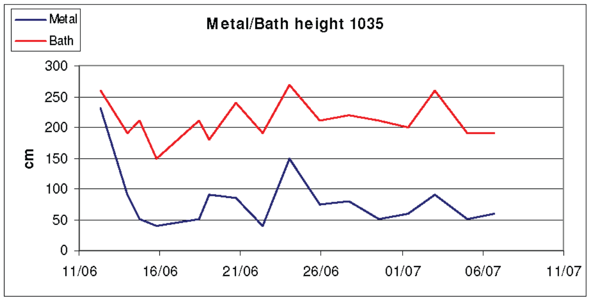

Figure 10: Metal and bath height development

As Figure 10 shows the liquid bath levels were at a high level (target = 20 cm). The increase in bath levels is due to the fact that cover material on the anodes the mixed with bath due to changing anodes. The metal inventory was initially high, because additional metal was poured into the cell to get the noise down.

After 48 hours the cell was eligible for changing anodes. From that moment the cell was covered with crushed cover material and alumina on top. The set-point voltage could be adjusted based on measured temperatures to the required level.

Generation of bath material

The generation of bath material of newly started cells went very fast. The generation of bath material went faster then expected and the number of cells that had an increased bath height in Potline 2 could be decreased very fast. This way the number of high iron cells could be avoided.

Conclusion

Preheating and fast restart of a large number of cells is a major and complex task. Thanks to extensive testing and highly motivated and knowledgeable personnel a fast start-up of 50 cells has been developed and executed successfully. A start-up rate of 1 cell per 2 hours is possible, once the gradual ramp up in line current has been completed. Several critical success factors have been identified of which the gradual increase in the line current is determined as the most important factor. Other factors are:

Number of cells

Critical factors on the number of cells that can be restarted simultaneously are: resources available for anode and cathode current distribution measurements, anode airburn control and the number of started cells that can be controlled at the same time during the early operation.

Liquid bath transfer

Especially at the start, the availability of liquid bath is another key factor. After the first cells have been started-up, fast generation of liquid bath enables fast start-up of the already preheated cells. Therefore it is critical to ensure a fast production and transfer of liquid bath.

Start-up team

Two separate teams that are responsible for the actual start-up and early operation respectively are needed for a good restart. A start-up team that has the focus on starting-up cells and a team that is responsible for aftercare. The aftercare team focuses on control of bath levels and bringing the cells to their normal heat balance.

Cell life time

It is expected that cell life is increased by doing preheat before start-up. By mid November 2010 no early failures occurred at any of the 47 cells that were restarted with the new method.

In retrospect it was evident that the soft restart method described in this paper resulted in improved process performance and longer cell life. Furthermore, it is possible to start-up a large number of cells because the method is easy. This raises the question about the design of a potline related to the lay-out and number of cells in respect to flexible operation. In general smelters tend to have as many cells as possible in a potline, but this makes it more difficult to frequent shutdowns and start-ups.

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