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UNIFORM CATHODE CURRENT COLLECTION / DISTRIBUTION EFFECT ON CELL STABILITY (NINE MONTHS OF CONTINUOUS TREATMENT OF A SICK CELL)

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Abstract

This paper describes a useful experience, which was conducted duringlast year's start-up and potroom operation regarding a sick cell treatment in an aluminum smelter in Iran, which we will call smelter X in this paper. Different parameters in the potroom have influence on cell stability, which need to be considered all together. Metal pad stability is the main concern for a smooth operation in an aluminum smelter to reach a low noise level and a high current efficiency. One of smelter X's aluminum reduction cells, which was started with good and smooth operating parameters, turned into a sick cell with a very high noise level two months after its start up. A special team started to monitor, test, analyze and try different strategies to bring the cell back to normal condition. This paper is a summary of the aforementioned challenge, team endeavor, possible solutions and final results to overcome this problematic issue.

Introduction

The circulating flows of both molten aluminum and bath in the cell are the main reasons for the back reaction contributing to lowering of the current efficiency. To ensure that a cell will have a high current efficiency, we have to implement stable conditions for the operating cell. The important aspect of stability means reduction of metal pad velocity as much as possible and keeping the metal in a flat shape in the aluminum reduction cell. This will help to keep the molten aluminum away from migration to the electrolyte bath, which can cause undesired back reaction and loss in current efficiency.

If we want to have a knowledgeable control and a smooth operation, it is important to have a simple image of what is happening in the aluminum reduction cell. One part of this image will be tracking of the line current pathway in the cell, which is supposed to be in the vertical direction from the anodes to the cathode. We need to minimize switching this vertical current to horizontal current as much as possible. Horizontal currents generate forces that will act upon the metal pad in the upward direction and cause the cell to become unstable [1]. Two possible factors that could be influential on making horizontal current in the aluminum reduction cell, which are related to the cathode are as follow:

1. The electrical resistance of the cathode blocks
2. Cathode block to current collector barscontact

The electrical resistance between the current cathode collector bars and the cathode blocks depends on the material that is used to join them together. Because of the chemical properties, physical properties, and in particular, the electrical properties of conventional cathode blocks based on anthracite, the poor electrical conductivity of steel did not have a severe process limitation until recently [2].Three parameters are important regarding cathodic electrical design and they are as follow:

1. Cathode bar / cathode block ratio
2. Cathode bar / cathode block length ratio
3. Cathode bar / cathode block electrical resistivity ratio

The aforementioned items are affecting the cathodic current distribution directly, and it is important to keep the cathodic current distribution uniform to make sure that we will have a stable cell with normal current efficiency. If we use high quality materials for cathode preparation, precise monitoring installation in the cell with controlling the quality of cathode block to collector bar contact before installation in the cell, and also ensuring the tight connection of the cathode collector bar to the cathode collector bar flexible (the cathode collector bar flexible, which is mostly copper, has been called finger in the rest of this paper) for uniform gathering of current from the cathodes, we could tell that there is no harmful effect from cathodes on cell stability for the entire cell life. However, the raw materials used in the cathode carbon blocks must have high density, good electrical conductivity, and be stable against attack by alkaline compounds [3].

Events Observation

Smelter X is located in the south of Iran and the plant was started in September 2009. The cell technology is D20 from Dubal and the normal voltage is 4.4 V for any single aluminum reduction cell with 230 kA line load. A process control team from Dubal and smelter X monitored the necessary items before start-up, such as collector bar installation in the cathode blocks and cell lining during construction. Everything was based on procedures, and tight control was done during construction and start-up.

Cell number 7 in the potroom was started on December 2nd, 2009. Installation, construction, preheating and start-up were smooth and approved by the process control team. During the first two months after starting up the cell, itscondition was changed to a critical situation several times. The cell condition was back to normal after removing a few spiked anodes from the cell periodically.

The cell was normal until the first week of February 2010, when we lost the cell control suddenly. The cell appearance was normal but the noise level was as high as 200 to 300 mV, and there wasno choice for potroom management except keeping the cell voltage high enough to be able to control the noise level. The main cause was not quite clear but it could be a line power outage that switched the cell condition to an unstable one.

Another event was lack of enough materials to keep the bath level in the range for a long time and this just happened right after cell number 7 showed instability. This could make the situation worse for the cell by not being able to provide enough bath to dissolve alumina for a long time. The condition was so critical and the noise level was high, which forced the potroom management to skip the scheduled metal tapping several times or sometimes tap smaller amounts of metal to be able to control the cell noise. After that a few times of power reduction and power outage made the situation worse and the cell then reached to a completely out-of-control condition. Figure 1 and figure 2 give the summary of eight months of struggling with cell number 7 to control its condition. It includes a trend of average noise level and average voltage for the cell. The figures show that for nine months, based on potroom management order, the cell voltage was increased in a step-by-step procedure and very slowly by cell ACD enhancement to control the cell noise level. However, the voltage was reaching up to 6.5 V but the noise level was still at an unacceptable level.

The voltage for a normal cell should be 4.4 V and the noise level should be as low as possible. During nine months the noise level was increasing for the aforementioned sick cell and this was getting totally out of control after any metal tapping. On the other hand, high voltage caused bath temperature shooting up, having red shell all the time, multiple and out of control anode effects, out of control alumina feeding trend and very high air burned anodes. The most problematic issue with a sick cell is its high voltage for the noise level control, which is affecting its anode change pattern due to high rate of air burning and anode burn off. Figure 3 shows the general condition of cell number 7 on its monitoring system during its first week of getting out of control. It shows high temperature, very high and unstable noise level (481 mV), extra anode effects, fluctuating voltage and working with long interval alumina feeding time (80 s).

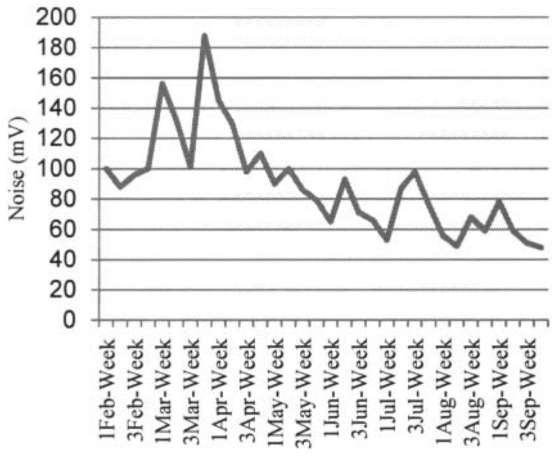

Figure 1. The average noise level trend for thesick cellduring eight months.

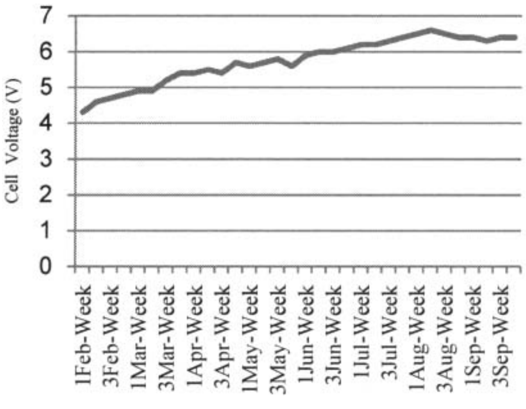

Figure 2. The trend of the average cell voltage for the sick cell during eight months.

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 4.56  223.0P   481   1433              2247
ea 1k sc un                        AM NC F4
 80s   0.122%  984°C                   4.4%
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Figure 3. Cell number 7 condition on the pot monitoring system.

Figure 4 shows the real condition of cell number 7, which has a high voltage, high ACD, and with long interval feeding time. The figure shows that the cell is suffering from a high and abnormal temperature.Performing anode cover will raise the cell temperature and because the cell was highly susceptible to long lasting anode effects, anode cover may be washed out immediately after each anode effect and this could make the cell condition worse than before. On the other hand, imperfect anode covering could make high anode air burning and that could bring the cell close to danger of high number anodes burn off and possible cut out, as it has been seen in figure 4. This was a real complicated situation and hard to make the decision of what to do.

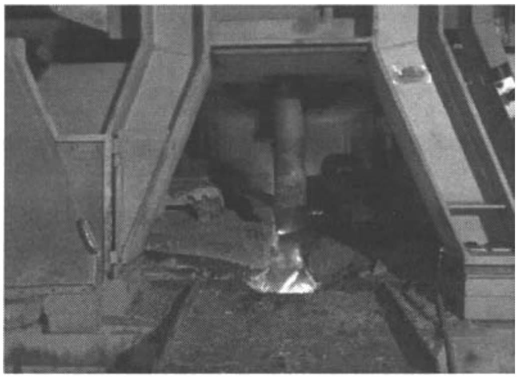

Figure 4. Cell number 7 conditions with high temperature, low amount of alumina feeding, high number of anode effects, high cell voltage and terrible anode air burning.

Methodology to Overcome the Problem

Smelter X was running out of enough primary bath material right after the condition of cell number 7 was out of control. This problem, which lasted for two months, caused the sick cell to be operated without enough bath and the situation reached a complicated step. At this period, which is explained as time period 1, the general strategy was taking care of the cell by all personnel participation as much as possible. We received enough materials to provide bath for the cell during the first week of May 2010. Since the cell condition then was worse than ever, potroom management decided to put a special team to work exclusively with this cell with a strategy of working step by step to try different aspects on the cell. Obviously, every single and small decision regarding this cell supposed to approve by that team to make sure we were able to track all activities and their results. The strategy steps are as follow:

A. First Strategy for the Time Period 1 (Dealing with the Sick Cell as a Normal Cell and performing a few Extra Actions)

The first step was between February and May 2010 and before deciding to put a special team in charge of the cell. Basically this strategy relied on monitoring the cell around the clock and trying different cures at different time periods. The cell was kept on locking anode movement and controlling the beam position all the time to make sure that the beam is not moving up and down and keeping the cell's resistance as constant as possible. The reason was that we believed that the cell voltage is high but that is not due to high ACD, so the high voltage is mostly because of unacceptable bath resistivity. This tight control of ACD was even done during metal tapping of the cell. To keep the ACD after tapping exactly the same as before tapping, anodes were brought down manually by personnel during the metal tapping operation. The procedures to help the cell condition during this period were as follow:

1. Check the anode current distribution all the time
2. Anode changing based on cell condition and not based on anode change schedule
3. Anode movement lock to keep the ACD constant, even during metal tapping
4. Alumina feeding control. Normal time interval is 48 s for feeding alumina to the cell but this time the interval was increased to 70 s for the sick cell. During this time period, the demand feed logic was disabled for this cell, since the cell was getting highly unstable when the feeding switched to super and overfeed time
5. Checking the automation system and wire control (It did not show any problem)
6. Since the anode effects were mostly too long and after anode effect quenching the bath level was high, we always followed a special procedure after quenching of the anode effects. The procedure includes anode changing, one or two anode isolation from the anode ring bus to make the cell stable, and set up the cell voltage as it was before anode effect and finally bath tapping.

Anode effects in this cell could cause the situation to become worse than before. After quenching the anode effect, controlling the noise level was not possible unless we insulated one of the kicking anodes or one of the corner anodes in the cell. Sometimes anode isolation lasted for one or two days since de-isolation brought the noise back to the high level immediately. If the isolation for one anode lasted for more than a day, we switched the isolation to another anode on the duct side, so there would be only one insulated anode at the same time in the cell. Figure 5 shows one unusual, frequent and long-lasting anode effects for the sick cell. The duration of the anode effect is shown at the bottom of figure 5, which is almost two hours long. Noise in the figure is shown in purple and smooth resistance is in red.

At this point anode adjustment for the kicking anode was making the cell condition even more miserable. Due to long lasting anode effects, we disabled the anode effect quenching logic in the computer controller to make sure that the cell was not overfed by injecting too much alumina during the anode effect quenching. Sometimes we had to put the cell on track with no alumina feeding for even a few hours to help the bath reach its original condition due to loosing the top crust completely after the long lasting anode effect.

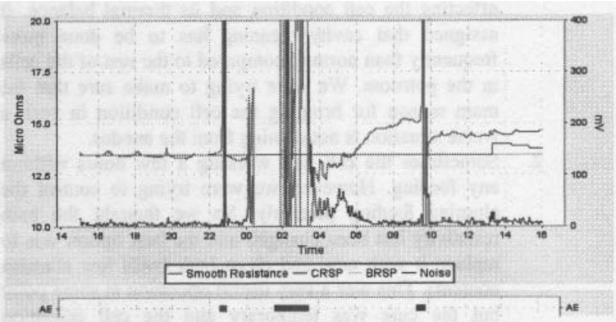

Figure 5. A frequent and long lasting anode effect for the sick cell.

During this period there was no acceptable improvement of the cell condition. Due to high voltage, the cell temperature was high, which was affecting the amount of metal tapping as well. Several times the metal tapping was skipped and this was affecting the line current efficiency as well. We were not able to cover anodes because of high cell temperature, short interval of anode changing and high frequency of anode effects. Figure 6 shows the general condition of the cell. As shown in the figure 6, smooth resistance should be kept high enough to bring the cell noise down. Whenever we were trying to bring down the cell voltage, the noise level was going up quickly. We could see an unusually high number of anode effects at the bottom of figure 6 during one day.

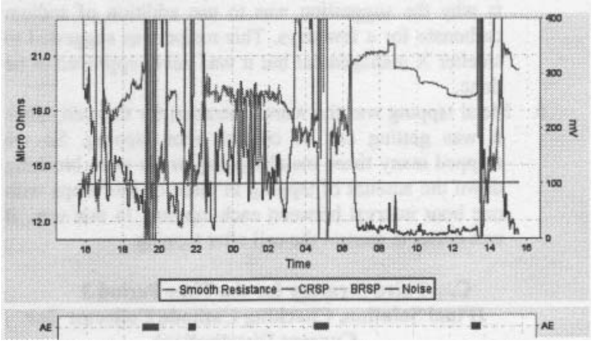

Figure 6. General cell condition, which was monitored by the controlling system.

B. Second Strategy for the Time Period 2 (Establishing a New Team with a New Procedure)

After four months of struggling to fix the cell condition, there was no sign of improvement and the procedures in previous strategy were repeated over and over again without any outstanding results. The cell voltage was high, and compressed air pipes were used to cool down the pot shell around the clock. More than five or six anodes were kicking at the same time, which we were not be able to adjust and we lost the adjustment of most of the anodes in the cell. A specially designated team was assigned to work with this cell, because it was then a possibility of losing the cell very soon. The procedure to deal with the cell during the next two months (June and July 2010) was as follow:

1. It has been designed a new and unique schedule to start changing anodes in this cell as soon as possible without affecting the cell condition and its thermal balance. It assigned that cavity cleaning has to be done more frequently than normal, compared to the rest of the cells in the potroom. We were trying to make sure that the main reason for bringing the cell condition in such a worse situation is not coming from the anodes.
2. Sometimes the cell was working a few hours without any feeding. However, we were trying to control the alumina feeding precisely. So we thought the bath resistivity has been changed and the best option was to replace it with new and clean bath (with low alumina content). This was a very useful operation at some point but the cure was temporary and the cell condition moved back to its uncontrolled condition again.
3. We were monitoring the cathode voltage drop accurately to track any changes. At this moment, we were suspicious about the cathode. However, the cathode voltage drop was fluctuating and at some point it was increasing but its increasing trend was not critical. Besides, we had some other cells with very high cathode voltage drop but the condition for those cells was normal.
4. We were consulting with some other companies around the world, such as Alcoa. Since the cell bath temperature was really high for a long time, it was believed that the generated heat is not distributed constantly in the cell. So all the heat is coming up from the top and the cathode is getting mucky and cold. That is why the suggestion was to use addition of sodium carbonate for a few days. This recipe was suggested to smelter X management but it was never approved to be done.
5. Metal tapping was the worst operation for this cell, since it was getting out of control after tapping. So we skipped many times metal tapping or we were breaking down the amount of tapping in three or four steps with one hour interval between each tapping. In this way, it was easier to control the cell after tapping.

C. Third Strategy for the Time Period 3 (Final Solution, Checking Cathode Collector Bar Current Distribution)

It was almost seven months in a row to deal with the tough situation we had with this sick cell. There was no other option to try except cutting the cell out and making autopsy to find out the problem. At this moment something interesting, which was never paid attention to carefully before, came to our mind. It was interesting to see that whenever the cell condition was getting worse with high noise level, the best way was to isolate or remove either corner anodes in the duct side or two other anodes close to them. After removing the anode from the ring bus, the cell was getting calm immediately and we could even then bring down the voltage. We assumed that there is no stable, downward passing current from the anodes to the cathode in a part of the duct side and there is a possibility of horizontal current in that side, which makes the cell noisy and unstable. At this point, we reached to a conclusion that there is something wrong with the cell cathode. On the other hand, we were dealing with a new cell, and experts from Dubal were monitoring the cell condition and its data during cell preheating, we started to think that the cell preheating was not done perfectly, as it has to be followed based on the procedure. It has been observed that the temperature distribution in the cathode after preheating influences the general operation of the cell, and to avoid "noisy" cells the temperaturedistribution should be as uniform as possible [4]. So the preheating data for the cell was checked completely and there was no sign of out of range data, especially for the cathode temperature in the entire cell. If we assumed that the cathode baking and the cell preheating were done perfectly at the final stage of our treatment, we needed to check all kind of voltage drops related to the cell cathode. Since the cathode voltage drop almost was close to normal range, we decided to measure the voltage drop between the cathode collector bars and the fingers (There are 38 fingers to be measured). The normal amount should be 40 mV, but we observed that the drop was more than 140 mV for all connections between collector bars and fingers in this cell.

An uneven current distribution can, among other things, be caused by bottom freeze and/or cracked cathode blocks. The end blocks are especially susceptible to bottom freeze and cracks, mostly prevalent as wing cracks. It may be debated if wing cracks in the end blocks can be a major cause of bottom freeze problems in this areasince thisloss of contact pressure results in less current density, which in turn leads to reduced internal block heating. Nevertheless, a plot of the ratio of current pick up in end bars to average collector bar current (in %) gives a warning of bottom end problems [4]. In figure 7 the relative end bar current pick up is plotted for the first 3-year period of two identical prebaked cells following thermal preheats, one developing satisfactory with very slow decline and one where the end blocks obviously have been damaged during preheat and/or start [4].

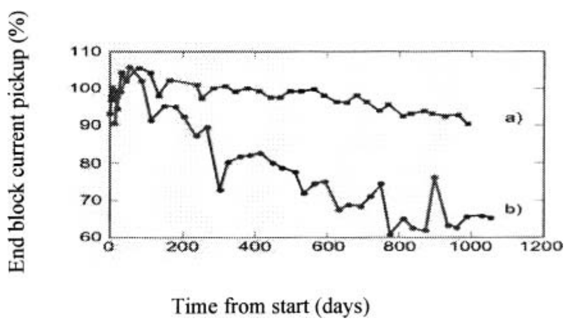

Figure 7. End block current pick up, in percentage of the average bar current, in identically lined cells during the first 3 years after start illustrates a) satisfactory and b) unsatisfactory progress. The latter may be due to wing cracks in end blocks [4].

The aforementioned voltage drops before and after fixing the connection of fingers to cell collector bars are shown in figure 8. The numbers in the horizontal axis are counted from the tap side upstream all the way to the duct side upstream (19 connections are in the cell upstream) and the rest are counted in the cell downstream from the duct side all the way to the tap side (19 connections are in the cell downstream). It is clear that all fingers drop are very much higher than normal for the entire cell but the average amount for the fingers in the duct side of the cell is higher than for the rest of the fingers in the cell. This is the proof of why the cell was getting stable and calm operation whenever we were isolating or removing anodes in the duct side.

A contractor was assigned to open the collector bars one by one, polish them, reconnect and tighten them again as much as possible. We started from the duct side where we saw strange observations. At the same time, we were controlling the alumina feeding and we were trying to replace the bath with a new and fresh bath. The cell came back to normal condition in less than a week when we finished the cleaning of half of the collector bars joints with fingers. We tried not to bring down the cell voltage immediately, because the cell condition was fluctuating rapidly. Thus, we made a schedule and procedure for decreasing cell voltage by lowering cell ACD based on its weekly condition such as bath level, metal level, metal production, noise,temperature, and amount of alumina feeding. Also, we were gathering anode current distribution and cathode collector bar current distribution data daily to make sure that we had all necessary information to make the right decision.

It is important to remember that to modify the current density distribution in the cathode, the principle is to generate a resistivity pattern in the blocks that will thwart the current tendency to become concentrated at the block end [5].

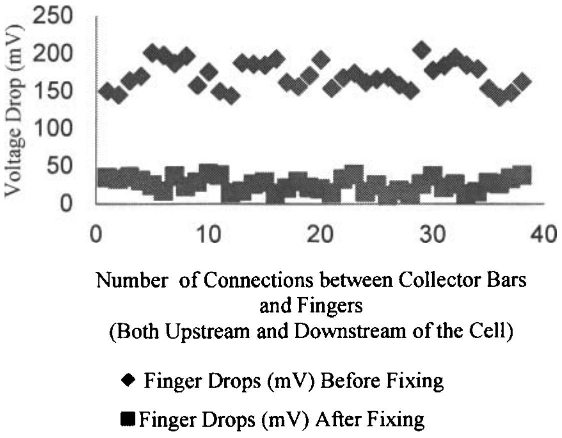

Figure 8. Fingers voltage drop distribution before fixing and after fixing (The fixing was opening, polishing and retightening the connections).

Discussion

This study was done during the smelter X plant start-up. All aspects of material procurement, construction, installation, preheating and start-up were under smelter X's and Dubal's close supervision. Cell number 7 turned into a sick cell after two months of operating in a great condition. Because we had no doubt about a perfect installation and preheating, we believed that power outage caused this situation but it still is not completely acceptable. The point was that we had a few times power outage again but the only cell that turned into a sick cell was cell number 7. The three steps strategy was assigned to help the cell back to its normal condition. When we were trying different aspects on the cell, we observed that corner anodes isolation or their removal from the cell in the duct side brought the cell back to its normal condition. Since the cell lining was not fully out of range, we assumed that the problem came from the cathode. By checking voltage drops between the cathode current collector bars and the fingers, we found out that the voltage drops were very much out of range. We polished and retightened these connections to bring down the voltage drop to its normal range. After that the cell condition changed to a normal cell and it never turned out to become a sick cell again.

Before	Anode Number from Tap Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Current Distribution (mV)	3.2	5.5	4.0	6.1	3.1-4.0	5-6.4	4.0	2-3.4	2-4 or insulated	8-10 or insulated
	Anode Number from Tap Side	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**
	Current Distribution (mV)	4.8	4.5-6.0	5.8	3.5-4.5	6.0	2.8-3.5	5.5	3.7-4.3	5-7 or insulated	7-8 or insulated
After	Anode Number from Tap Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Current Distribution (mV)	4.9	2.8	3.5	3.7	4.1	4.4	3.1	5.0	4.6	3.0
	Anode Number from Tap Side	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**
	Current Distribution (mV)	3.1	5.5	4.1	3.3	4.9	5.1	4.3	3.7	5.1	3.9

Table 1. A typical anode current distribution for the cell number 7 when it was sick (Before) and after fixing (After). The normal range for anode current distribution is 3.0 to 5.0 mV. When the cell was sick, only one anode from cell duct side was insulated at the same time.

It is interesting to see the cell condition by comparing anode current distribution before fixing the sick cell and after getting it back to its normal condition. For a 230 kA line current, the normal range for an anode CD in a cell with 20 anodes should be 3.0 to 5.0 mV. When the cell number 7 was sick, the current in more than three anodes was fluctuating rapidly almost around the clock. It was very difficult to check the anode current distribution and make the decision about correcting the anode position in the cell. We believed that the fluctuation for the anode current distribution has a reason other than anodes problem, and we were not trying to play with the anodes' positions. On the other hand, anode current distribution was getting out of control in almost every anode in the cell after metal tapping. Thus, we had no other choice than to insulate one of corner anodes in the cell duct side, especially after metal tapping. Most of the time, we had one anode insulated in the cell and we were rotating the insulated anode every 24 hours among four anodes in the cell duct side. As it could be seen in table 1, the typical cell anode current distribution was normal and in the acceptable range after finding the main problem for the sick cell and fixing the cathode collector bar current distribution.

It can be seen in figure 9 the general condition of cell number 7 after fixing its collector bar current collection. The normal super, over and underfeed are shown in the upper part of the figure. The lower part of figure 9 is the slow and stable movement of cell noise and smooth resistance, which is a good reference if we compare it with the cell condition before treatment in figures 5 and 6.

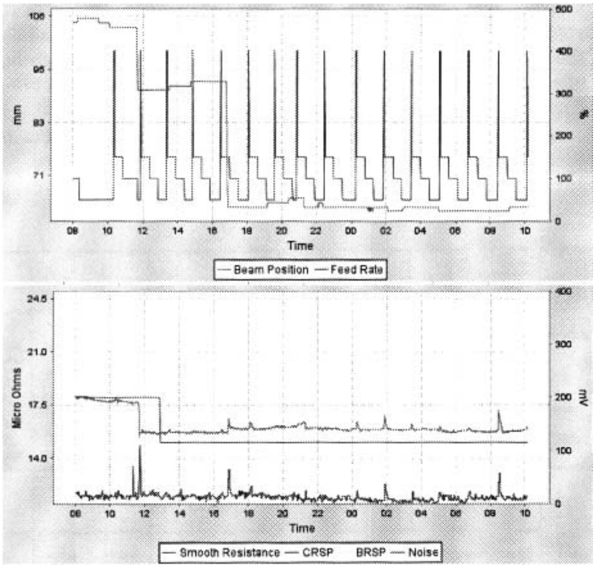

Figure 9. Cell general condition after finalizing treatment including regular feeding, low level noise, and regular smooth resistance fluctuation.

Conclusion

It is important to consider all aspects of an operating cell when we are dealing with a sick cell. Since the cell was getting out of control during start-up, this made it complicated to figure out what was going on with the cell. All efforts were conducted to bring the cell back to its stable condition. However, increasing ACD and cell voltage were the easiest ways to try to bring the cell back to the stable condition again, but it was a temporary solution. In this case, we kept the voltage high to have the cell stable as much as possible and then we were trying different cures on the cell. As much as anode changing operation and their adjustments are important for the cell stability, vertical current from anodes to the cathode and uniform current collection by cathodes have the same effect. The connection between the collector bars and fingers for the aforementioned cell was not checked accurately before start-up, so one quick poweroutage turned the cell unstable for a long period.

Acknowledgment

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