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MEASUREMENT OF CATHODE SURFACE WEAR PROFILES BY LASER SCANNING

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Abstract

The service life time for high amperage aluminium reduction cells with graphitized cathodes is limited by cathode wear. The wear is normally very non-uniform, and it is commonly documented by photography and/or manual point measurements. In an attempt to record the wear pattern in a much more detailed way, a laser scanning procedure was developed. A laser scanner with a single point accuracy of 10 mm has been used to produce a 3D model based on three overlapping scans with an average resolution of about 1 cm. The same cathodes were also measured manually for comparison. The method developed gives detailed information regarding the wear at different positions within the cell, and it may become a valuable tool for investigating the influence of different parameters on the cathode wear.

Introduction

The very non-uniform wear observed in aluminium cells with graphitized cathodes is today limiting the cell life and it represents a great challenge for the aluminium industry.

The so-called w-wear profile is reported by several authors [1,2]. The mechanism for the wear observed is still not fully understood. It seems clear, however, that current densities and metal/bath movements play important roles together with the formation and dissolution of aluminium carbide. Higher wear is observed in areas with high current densities. The ramming paste between the cathode blocks normally shows less wear.

The documentation of the observed wear is usually made by photography and manual point measurements. This gives a crude overview of the wear pattern with little preservation of details. Therefore, there is a need for a new method which is more detailed and provides documentation that can easily be studied in retrospect. In this work the laser scanner method is reported and compared with a manual telescope leveling method. Both methods have been used during post mortem investigation of two cells at the Hydro Sunndal aluminium smelter.

Cells, Measurements, and Procedures

Cells

Two cathode linings (D105 and D107) from Hydro Sunndal Al plant (SU4) were investigated with respect to cathode wear profile. The cell design for both cells was similar and the surfaces consisted of 19 graphitic cathode blocks with ramming paste in between. Both cells were shut down due to high levels of iron in the metal. The cells were considered to be run under normal electrolysis conditions during the life time, which were 2088 and 2184 days, respectively. Pictures of the cathode surfaces of both cells are shown in Figure 1. The cathode surfaces were thoroughly cleaned before measuring started.

Cell D 105 (2088 days) Cell D107 (2184 days)

Figure 1. Cathode surfaces of cells D105 and D107.

Laser Scanning Method

The laser scanning method offers the possibility to capture a surface of an object — in this case a cathode — in great detail. It is a non-contact active measuring system which acts by sending and receiving laser light. The scanner shoots a laser beam and collects the reflected light. The result is a point cloud consisting of a resolution dependent number of points with 3D coordinates and often some additional attributes as well. One distinguishes between mainly two kinds of laser scanners which work with different techniques: triangulation and time-of-flight laser scanners.

A time-of-flight laser scanner, such as the one used (Riegl LMS-Z420i [3]), measures the time t a laser pulse needs to travel from the sender unit to the target surface and back to the receiver unit, and thus the distance d can be calculated.

$$d = ct / 2 \qquad c\text{: speed of light}$$

Together with the known horizontal and vertical angles - analogue a total station (tachymetry) - 3D coordinates can be computed. A laser scanner beam will be reflected from the first object it hits; hidden objects cannot be measured (shadow effect). Therefore, it is often necessary to work with more than one scan position.

The terrestrial time-of-flight laser scanner used in the present experiments has a measurement rate up to 11'000 pts/sec; measurement range 2–1'000 m; field of view 80 x 360 degrees, and it consists of a fixed lower part (in this case mounted on a custom-made frame) and a rotating upper part analogous to a tachymetrical total station. The generated laser beam is diverted by a rotating respectively oscillating mirror. After measuring a vertical line with a given resolution/angle, the scanner turns horizontally at a given angle and continues scanning the next vertical line, as illustrated in Figure 2.

A calibrated digital photo camera Nikon D200 (f=20mm, 10.2 megapixels) was mounted on the scanner, making it possible to incorporate RGB values for the points obtained by the laser scanner.

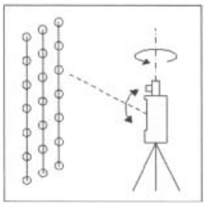

Figure 2. Principle of the laser scanner.

Laser Scanning Configuration and Procedure

A custom-made steel frame constituted the platform for the laser scanner (Figure 3). With the help of a crane or a digger it was mounted on the steel shell of the cathode, and the laser scanner was fixed at the top. The construction could easily be moved along the pot shell while the laser scanner was attached.

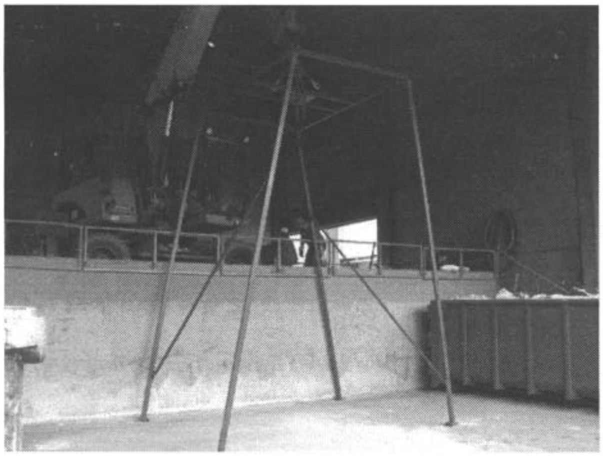

Figure 3. Steel frame for placement of the laser scanner.

To obtain data for the entire cathode surface with approximately the same resolution and to avoid shadow effects, scans from three positions with overlapping areas were performed (as illustrated in Figures 4 and 5). 20-30 circular tape reflectors (target points) were distributed on and around the cathode to help aligning the three overlapping scans. This configuration also enhanced the point accuracy (the single point accuracy of Riegl LMS-Z420i is 10 mm). At each scan position a scan with a resolution of 0.05 degrees (approx. 5 mm at a distance of 6 m) was executed, and photos were automatically taken for the corresponding surface as well.

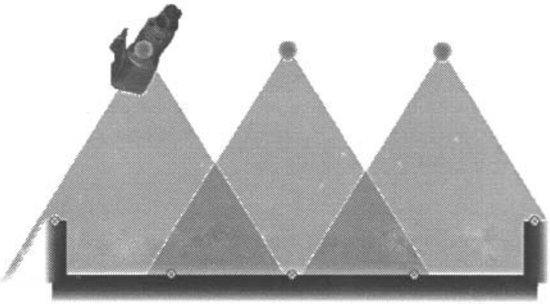

Figure 4. Laser scanner positioning above the cathode.

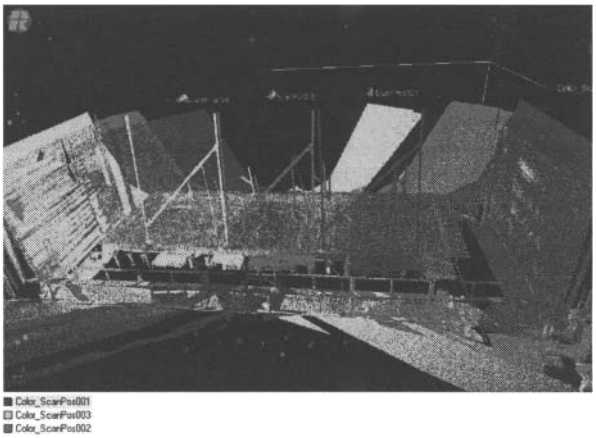

Figure 5. Three overlapping point clouds - the cathode, the steel frame and the surrounding area are visible.

Data Processing

To be able to get accurate results from the data processing of the geometrical laser scanning data together with the photos taken by the calibrated camera, calculation of the camera mounting calibration (camera position related to the scanner) was essential. Therefore, these calibration values are calculated for each of the three scan positions by using the scanned targets. Each point cloud (one per scan position) is then coloured by the photos taken at the same scan position. The working step 'registration' links together the different scan positions via the targets they have in common. This registered total point cloud had 3D coordinates (XYZ) in a casual local coordinate system which was then transformed to a cathode-adjusted one. For this step the three single point clouds had to be re-registered to one total point cloud.

The transformation results were as follows:

Standard deviation [mm] - Cell D105:
Point cloud 1 to new coordinate system: 3.2 (16 targets used)
" 2 " 2.6 (19 ")
" 3 " 3.1 (19 ")

Standard deviation [mm] - Cell D107:
Point cloud 1 to new coordinate system: 1.8 (27 targets used)

"	*2"*	*2.0 (29")*
"	*3"*	*1.8 (25")*

Useless or even disturbing points were deleted and the data were merged to one single 3D point cloud (5.3 million points). By using the scanner related software *RiScan Pro* and other programs, various types of visualisation could be obtained (using points and/or the triangulated surface).

Manual Method with Leveling Telescope

The current method for measuring the cathode wear profiles at Hydro Sunndal makes use of a leveling telescope and a measuring stick with a bubble level attached. The leveling telescope is placed on a stable surface outside the cathode shell from where one can read the measuring stick, which is placed at different locations on the cathode surface. On each corner of the steel shell there are reference points, from which the original depth of the newly installed cathode blocks is known. The difference in depth before and after operation can then be measured at several points on each cathode block. The typical number of measuring points is 7 points per cathode block, covering the deepest points on the sides, the highest point in the middle and the local high and low points in between.

The cathodes investigated in this work consisted of 19 cathode blocks, giving 133 measuring points. A team of three persons, one operating the leveling telescope, one holding the measuring stick, and one taking notes, needs about one hour to measure one cathode.

Results

Topographic Plots with Laser Scanner and Manual Method

Besides the forever reusable 3D point coordinates including additional values (i.e. intensity, RGB), saved in a common ASCII format, various meaningful products were created. For example 3D visualizations of the cathode where the point cloud is coloured by RGB were made (Figure 6), as well as a 3D model coloured according to the height or respectively the depth of the cathode surface (Figure 7). Also better known visualizations as i.e. height curves or horizontally and vertically surface cuts were calculated.

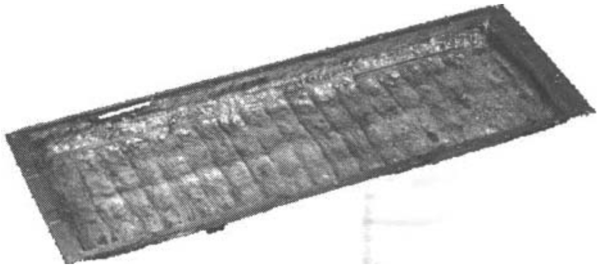

Figure 6. RGB-coloured scan data of cathode (Cell D105).

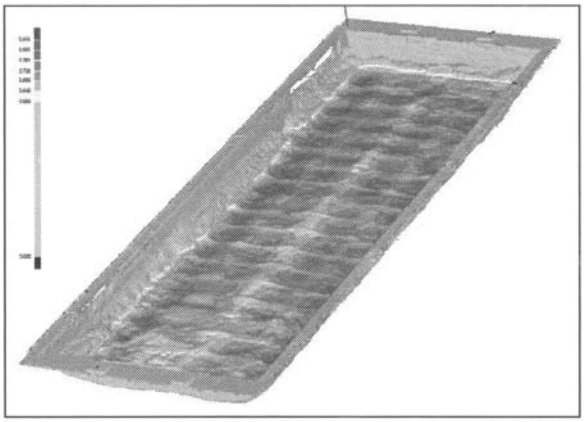

Figure 7. 3D model colored according to the depth of the cathode.

The 3D point coordinates from the laser scan were post-processed using Perl (a public domain data processing language) to resample the data to XYZ values at 1 cm resolution on each axis. The resampled data was converted to a grayscale image, where each pixel XY coordinate (column and row) corresponds to the respective XY position in cm, and the Z value (gray level) corresponds to the respective Z depth in cm. This picture was opened in the public domain image analysis program ImageJ for further visualization and plotting. These programs were chosen for convenience; the data could also have been plotted in other data plotting or image analysis software.

The manual method gives a set of XYZ values, where the X and Y values represent the measuring positions on the cathode surface and the Z values are the measured cathode depth. The amount of data is relatively small (133 points in this case), and interpolation is needed to create a good visualization of the wear profile. Just like the data from the laser scans, the data from the manual scans can be plotted like 3D models and contour plots. In this work linear interpolation was used to fill in the gaps between the measuring points. The data in the Z direction is quite reliable; the X and Y coordinates are usually not. For convenience the X values are determined by the cathode block number and the seven Y values on each block are assumed to be the same for every cathode block. In reality these points are not in the same spot on every cathode block. The measuring stick is typically placed at the deepest or the highest point (i.e. the most interesting point) in the relevant area to be measured. It is also worth noting that the less worn ramming paste between the cathode blocks was not measured with the manual method, according to the standard procedure.

The two methods are compared in Figure 8 and Figure 9. The pictures are sized and coloured using the same scale, from blue (highest) to red (deepest). It can be observed that while the average values are similar, the laser scans are much more detailed. The perimeter of each cathode block can be seen as areas of less wear in the laser scans. Obviously, this information is lacking in the recordings from the manual method.

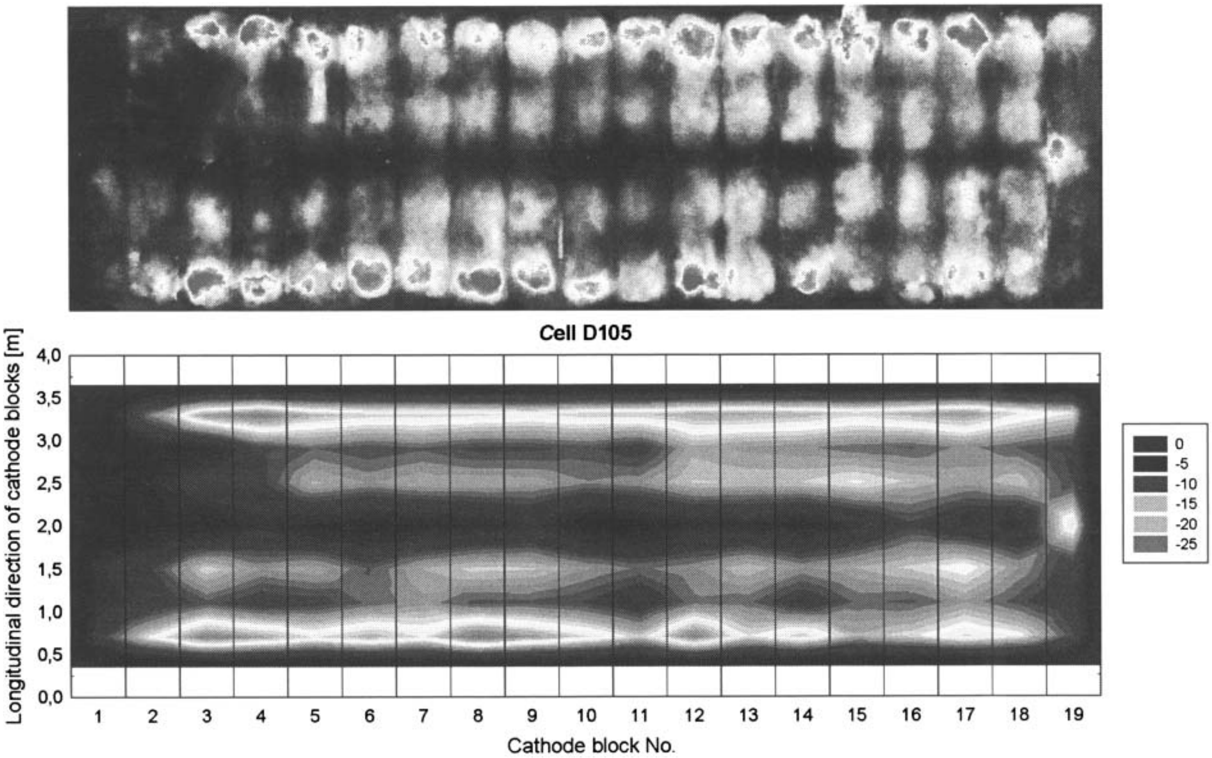

Figure 8. Comparison of the laser scanning method (top) and the manual measurement method (bottom) of cell D105.

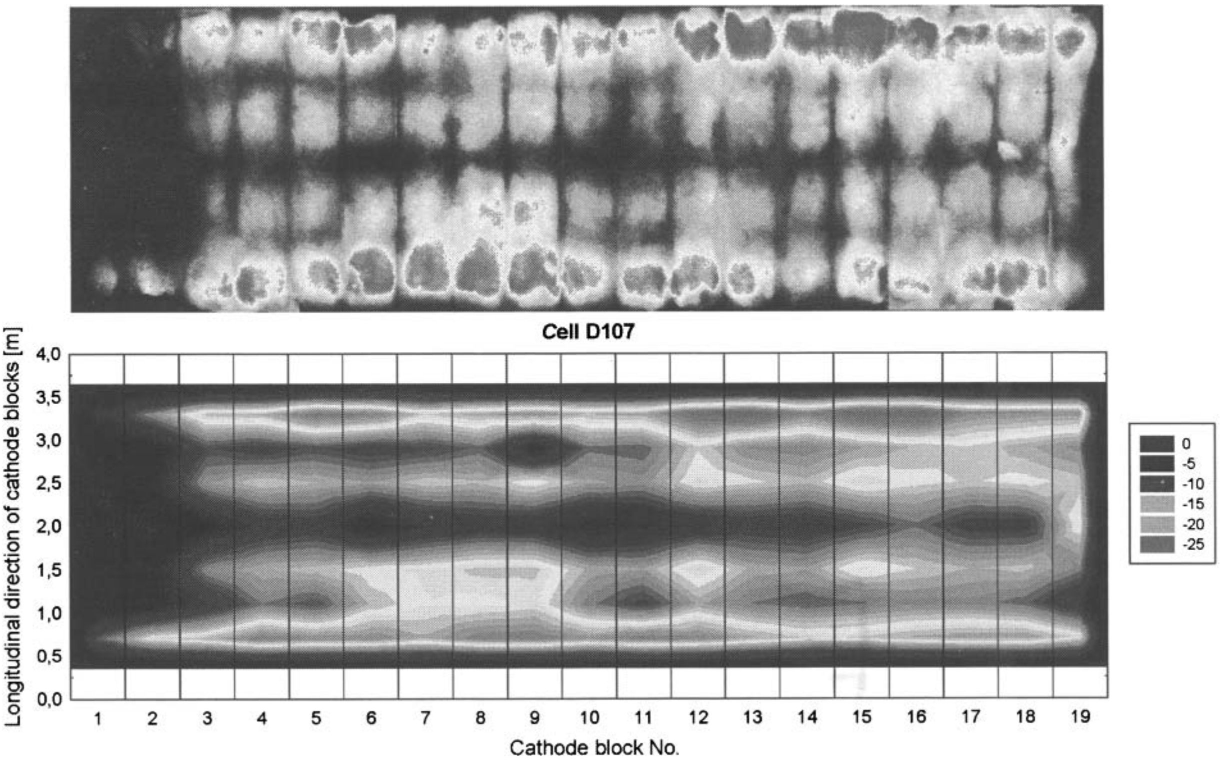

Figure 9. Comparison of the laser scanning method (top) and the manual measurement method (bottom) of cell D107.

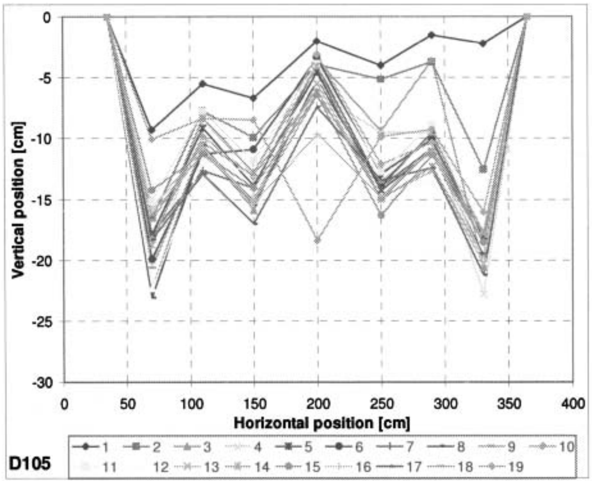

Figure 10. Wear profile of all 19 cathode blocks in cell D105, manual measurements method.

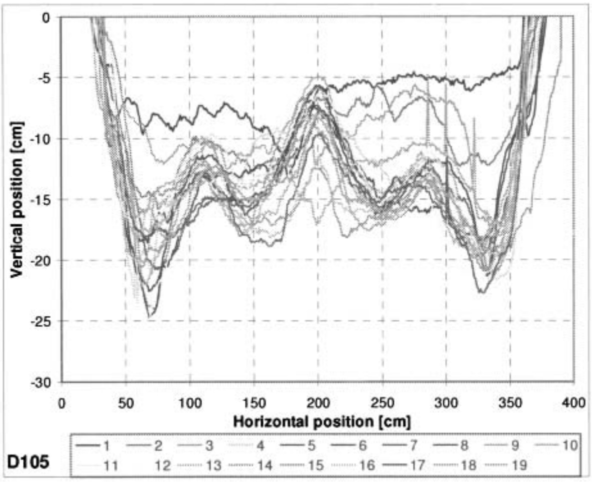

Figure 12. Wear profile of all 19 cathode blocks in cell D105, laser scan method.

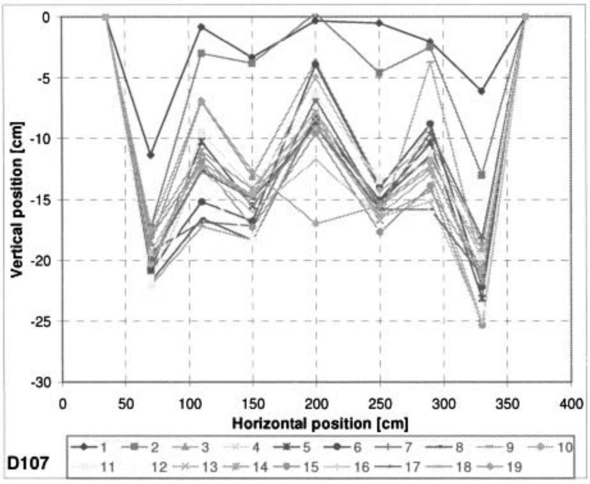

Figure 11. Wear profile of all 19 cathode blocks in cell D107, manual measurements method.

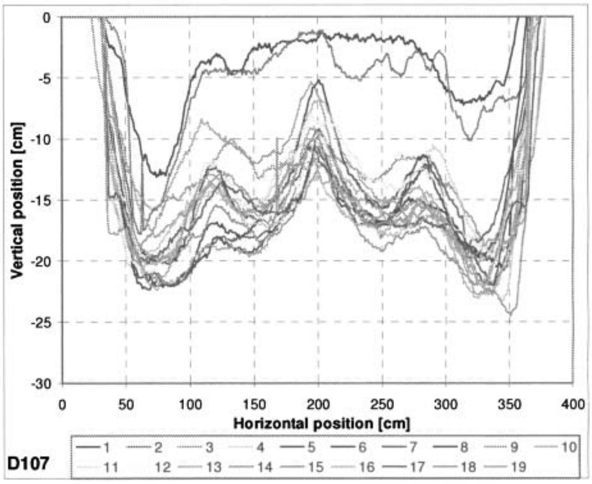

Figure 13. Wear profile of all 19 cathode blocks in cell D107, laser scan method.

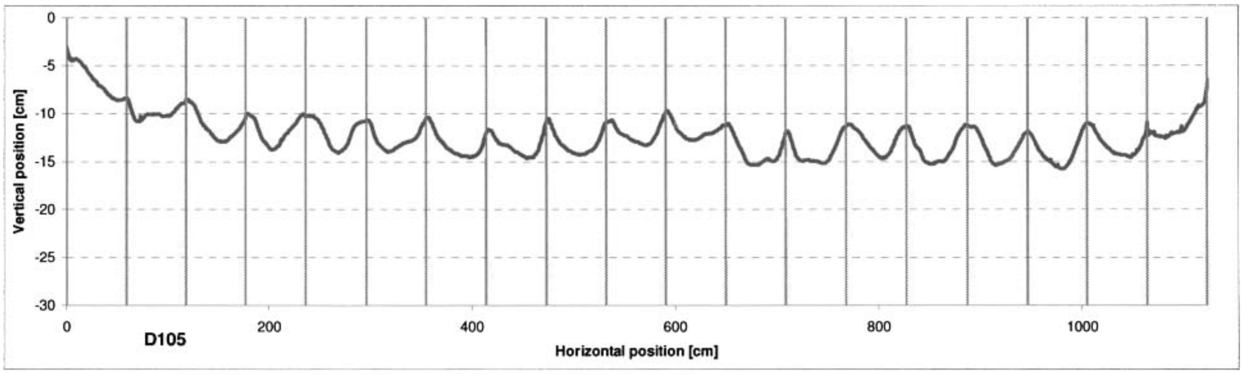

Figure 14. Wear profile lengthwise of all 19 cathode blocks in cell D105, laser scan method. Vertical lines indicate cathode bar separation.

Wear Profiles, Laser Scanner and Manual Method

A plot of wear profiles on each single cathode block numbered from 1–19 for the two cells by the manual method and laser scanning is shown in Figures 10–13. The initial cathode level before operation is used as reference and cathode heave has not been taken into account. Positive values mean that the cathode level after operation is higher than the initial level, which is a result of cathode heave. By assuming that the contribution of cathode heave is the same for all the measuring points, the cathode wear plots show good correlation with the real wear pattern of the cell.

Line plots of the data set from the manual method in the longitudinal direction of each cathode block reveal a general trend for both cells; a WW-profile, as shown in Figures 10 and 11. The same trend can be seen from the plots obtained from the laser scanning data shown in Figures 12 and 13. Cathode blocks no. 1, 2 and 19 stand out; 1 and 2 being less worn and 19 more worn in the mid section of the block. Cathode block no. 19 is located at the metal tapping end of the cell, while block no. 1 is at the suction end. Figures 15 and 16 compare line plots from the two methods for two single cathode blocks.

A plot of the wear profile in the longitudinal direction of the entire cathode is shown in Figure 14. It is evident that the ramming paste between the graphitic cathode blocks is less worn.

Summary

The laser scanning method gives several advantages:

- Much more detailed measurements than the manual method.
- The detailed wear pattern and shape of the cathode surface can easily be visualized in several ways.
- The high resolution makes it possible to zoom in and study local areas inside the cell (for instance tap pot holes or other local areas of interest).
- Wear profile plots can easily be made with high accuracy at different positions within the cathode surface inside the cell.
- Local areas of high wear (weak points of the cathode) are easily found.
- If the extent of cathode heave is known, the average cathode wear rate and the total carbon consumption can be easily and accurately estimated.

The more detailed measurements give more information and may provide more knowledge regarding cathode wear phenomena. Especially when considering modelling data of metal flow, cathodic current density, alumina distribution and also type of cathodes and linings the wear can be explained in a better manner than before. We regard that this method will be a valuable tool in deriving the mechanism for cathode wear in aluminium cells.

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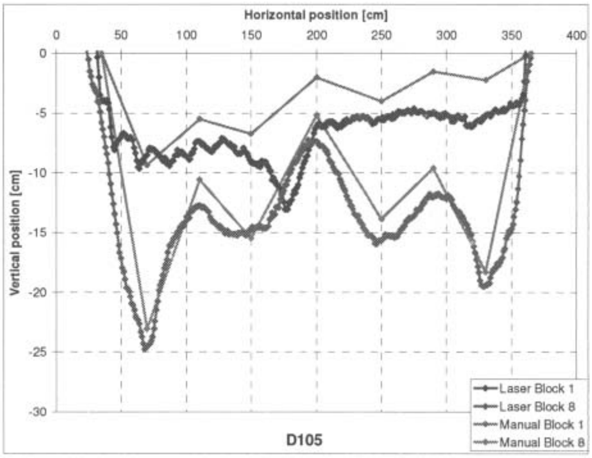

Figure 15. Wear profiles of two selected cathode blocks in cell D105, comparing laser scan and manual measurement methods.

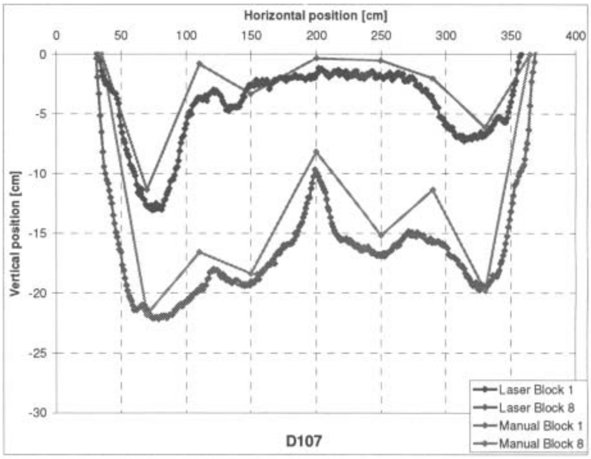

Figure 16. Wear profiles of two selected cathode blocks in cell D107, comparing laser scan and manual measurement methods.

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