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AN INNOVATIVE POT RAMMING MACHINE

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Abstract

Ramming paste around cathode blocks of Hall-Héroult electrolysis cells is considered a critical step to avoid premature infiltration and maximize the useful life of cells. To optimize the uniformity of compaction and make the task easier, this operation is typically assisted by equipment commonly called Pot Ramming Machines.

Lately, STAS has concluded a development project with the objective to offer the industry an alternative to the commercial systems available, with improved performances and innovative characteristics. The emphasis has been to deliver better operability, up-to-date quality control, easier mobility and maintenance, and improved capability in terms of compaction.

This paper presents a summary of the development work from prototyping through the selection of operating parameters, the qualification of compaction and the design and manufacturing of a full scale Pot Ramming Machine now available to the industry.

Introduction/History

In recent years, the aluminum industry has witnessed significant evolutions in pot technologies, which have been driven forward through ongoing research to increase production and process efficiency. The amperage of existing plants have been continuously increased to new heights, and newly designed pots operating at much higher amperage are emerging in an increasingly competitive technological environment.

To support these changes in cell operating conditions, considerable efforts were put into the design of the pots, for instance with the use of preformed side-blocks, or with the development of improved ramming pastes.

This created an opportunity to review the pot ramming operation in terms of equipment and tools, and therefore an internal development project toward a revised approach to pot ramming was launched. The objectives followed from two main axes: process and quality control, and equipment operability.

With respect to the design of the equipment, the objectives were focused on EHS considerations at first, considering noise levels and overall ergonomics as basic criteria. Then, minimum maintenance, high reliability and maintainability were embedded in the design philosophy.

However, the ramming process by itself was the core issue of the project, therefore the focus was on the quality of compaction as well as flexibility for users to optimize, with build-in quality control that creates a complete mapping of the lining joints and seams.

The project was driven by an open-minded approach, revisiting the basics of compaction, looking beyond preconceived ideas, yet considering the need of the industry for proven concepts in a competitive market. To secure the defined orientations, a thorough experimental procedure was followed from laboratory trials through prototyping, leading to a full-size prototype and real pot compaction.

Process Improvement

Paste ramming was originally done manually using a pneumatic hammer. This compaction method could be considered as “impact compaction” with very low frequency and high surface pressure.

Pot ramming machines, which have been in use for more than 30 years, greatly reduce the workload of operators. They also have the benefit, if operated correctly, to increase productivity and, more importantly, repeatability in the work. There are two different compaction methods for machines of the current generation: vibrocompaction and compaction by static pressure.

In the design process of a new pot ramming machine, the first step was to determine which compaction method provided the best performance. Ramming process was deeply analyzed and studied. Ways to test and analyze the compaction work effectively were found.

From civil engineering literature and the study of the properties of the paste, which is cohesive, porous and granular, a combination of static pressure and medium frequency vibration has been determined as the best way to homogeneously compact thick layers of paste. Trials would later on prove that hypothesis. On road work sites, for instance, machines are designed with adjustable frequency and eccentric weights to modify the amplitude and frequency of the compaction movement. This gives operators or supervisors the ability to adjust parameters depending on the condition and thickness of the asphalt.

Ramming paste lining undergoes significant mechanical stresses during the start-up phase of a pot. Depending on its properties, the paste may shrink slightly with baking while also being compressed from the expanding cathode blocks. Heat distribution at start up plays a major role in preserving the linings, but the rammed paste must beforehand be at the right density. Homogeneity of the compacted lining is also of primary importance since the internal stresses need to be evenly distributed. An undensified area or even voids would allow the nearby compacted paste to expand into the area and thus change the whole stress distribution of the pot.

Over compaction, either on top of the layers by a lack of homogeneity or through the whole lining can be just as detrimental. Layers not bonded correctly may tend to separate while shrinking or while subjected to the compressive stresses, which may potentially cause cracks or voids, thereby enabling aluminium or bath to enter the free space.

In order to obtain a specific density after baking, the density of the rammed paste before baking must be within a certain range. This density is measured during operation by measuring the volumetric compaction levels. This method has the advantage of being a non-destructive test, but the quality of measurements depends largely on the density before compaction. This is why a 10% variation in compaction – from 45 to 55%, for example – is acceptable.

The uniformity of compaction cannot be measured or analyzed without a destructive test. For this reason, we believe there is room for innovation, in a pot ramming machine, in terms of compaction homogeneity through better machine control.

Throughout the development phases, experts from the industry were contacted, including the valuable support of Rio Tinto Alcan's *(AP - Aluminium Pechiney)* representative for the analysis and qualification of compaction samples.

Experimental Procedures

Following some laboratory trials and concept validations on the behavior of ramming paste, a full scale bench test was designed and built to understand the phenomenon of compaction of the paste and to have the opportunity to test the effect of numerous parameters such as vibration frequency, dynamic load, static load and amplitude.

Besides our quest to obtain compaction parameters, various mechanical concepts could be tested during the development phase to make sure that our requirements for vibration isolation were being met. This would result later in noise reduction. Figures 1 and 2 show pictures of the test bench in its latest configuration.

Figure 1. Full scale compaction bench test.

The test bench allowed adjustments with a complete array of compaction parameters, with a combination of static pressure and dynamic forces and the possibility to analyze different approaches. The reader will find in what follows a general overview of the different paths followed during the trials.

Figure 2. Cathode joint compaction on bench test by using two anodes from a P155 pot.

A first trial field consisted in trying to understand the behavior of ramming paste under pure static loading, using a pressure-adjustable hydraulic system. This system allowed the evaluation of compaction under various levels of static loading, which proved inadequate when the layer thickness was more than 100 mm. The behavior of the rammed paste could then be depicted and analyzed, showing, as expected, serious inconsistencies from the bottom to the top of the layer. Porosities could be observed throughout the layer. Just as expected, and according to technical literature, vibration was needed to rearrange the particles at the same time as the load application to eliminate the porosities.

For the generation of dynamic forces, industrial-grade counter-rotating eccentric weight exciters were incorporated to the bench test, replacing a first version of a custom-made exciter gearbox. The flexibility of adjustment, both in terms of frequency and eccentric mass, allowed the evaluation of a full spectrum of dynamic conditions. Two vibrators mounted next to each other synchronize themselves at startup. Considering the very low cost, the ease of maintenance and the flexibility of adjusting dynamic loading, the concept was carried over to the final design.

All along the trials, sophisticated instrumentation for vibrations, displacement, speed and time, was used to efficiently monitor and record the operational data and understand the compaction patterns. More specifically, these measurements allowed for the optimization of the compaction parameters as well as a reduction in the transmission of the vibration.

After numerous tests and some advances, the test bench allowed the trial and validation of a design based on a pneumatic suspension concept, combining a pneumatic loading to a heavy dead weight in order to maximize the vibration isolation while giving the required static loading. This led to the current ram concept that will be described later.

Overall, hundreds of joints have been compacted while bench testing, with variations in terms of vibration frequency, dynamic and static loading, and vibration time.

While most trials were performed on cathode lining with 200 mm thick layers measured before compaction (a usual thickness in the industry), many trials were performed on 300 mm and even 400 mm thick layers to analyze the possibility of eliminating one layer to bring substantial cost savings. Although in-field trials would be required to confirm this approach, the results showed a clear potential as it was proven that a first layer at the bottom of the cathode lining of 400 mm thickness could be compacted to qualified density and homogeneity. With the ability of the machine for tuning the compaction parameters, a completely new field of pot ramming optimization can be considered. For instance, one could imagine that the bulk paste spreading could always be flush to the top of the cathode, easing the task as well as facilitating quality control.

Another domain where efficiency gains could be envisioned is the number of compactions per layer. A common practice in the industry is to perform 3 compactions of 10 seconds on each layer of cathode lining. Many trials have been performed, with 2 compactions of 10 seconds, with excellent results. Good positioning of the compaction tool proved to be the major factor allowing only 2 compactions instead of 3.

Throughout the trials, specific measurements were made to ensure an objective qualification of the compaction. Compacted joints were opened and inspected for layer cohesion and density measurements. A custom-made penetrometer was used for relative measuring. Specimens were even tested for density, with water displacement measurement, to make sure that the methods used to measure the compaction levels were appropriate. Figure 3 and 4 show examples of measurements.

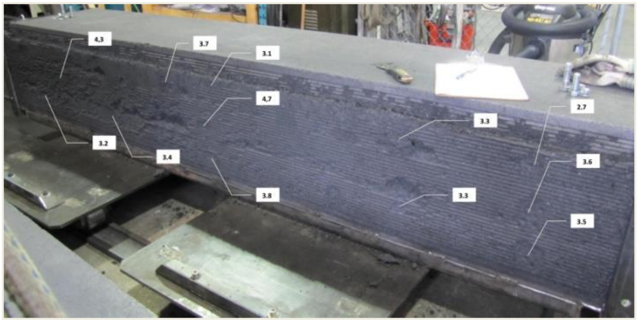


Figure 3. Hardness measurement through an entire cathode joint.

Determining the operating window of our equipment allowed experimenting with parameters leading to under- as well as over-compacted paste. A known fact in pot lining is that high frequency, high dynamic and static forces, when combined with an excessive compaction time, will easily break down the ramming paste, leading to over-compaction. The paste binders become insufficient for the added surfaces of the broken aggregate particles, and the paste loses some of its cohesive properties. Homogeneous compaction through a layer thickness is of primary importance for subsequent layer bonding. An over-compacted top layer with broken particles will not bind correctly during baking.

Figure 4. Custom-made hardness measuring instrument, commonly known as a penetrometer, used mainly to compare different compaction works and check compaction homogeneity through a layer.

Trials have been made in an effort to better qualify layers bonding. Dynamic parameters have a big impact on the quality of the bonding, but experiments have shown that the tool may also play an important role. Some trials have been performed with various tool designs (Figure 5). The goal is to avoid discontinuity between the paste layers which can become pathways for metal or bath penetration. We believe that to further analyze the layers bonding, baking must also be performed on the test samples, which could be done in a near future.

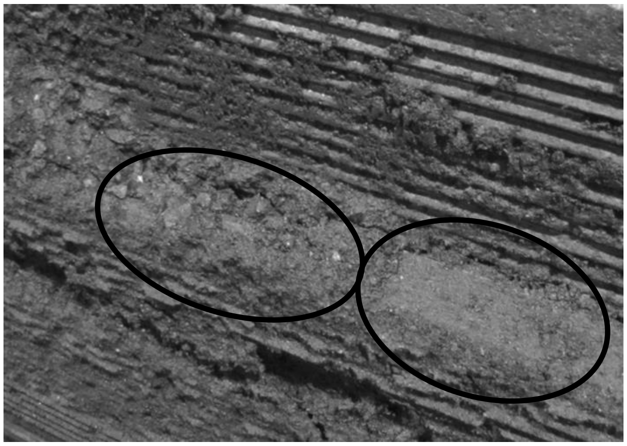


Figure 5. On the right, the top of a typical layer surface after careful removal of the subsequent layer. On the left, a much stronger layers bonding.

Compaction curves were retrieved from the instrumented bench test in order to make comparisons between various parameter changes (Figure 6). Our curves were used in relation with the rammability index of paste as detailed in the ISO standard 17544 and correlated with the curves from the Fischer Sand Rammer (FSR) equipment for a specific paste (Figure 7). The goal was to determine if it would be possible to use a feedback from the quality control system, automatically record the curves, and stop compaction just at the right time based on the shape of the curve. This would ensure that the paste is neither under or over-compacted. Large discrepancies with the curves would signal an error and require an inspection. Although the development work in that area is not completed, signs are positive enough to believe that further work could lead to other gains in terms of quality.

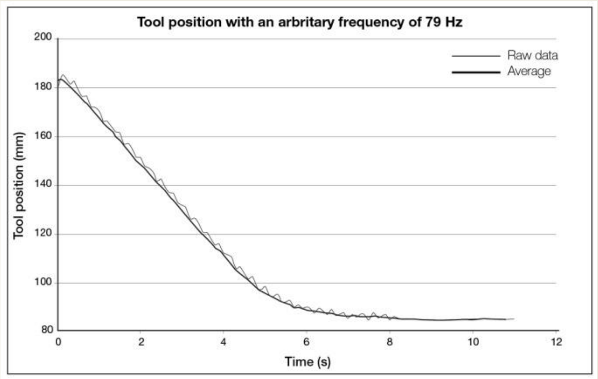


Figure 6. Position of compaction tool in time; the major compaction work is starting at approximately 4 seconds.

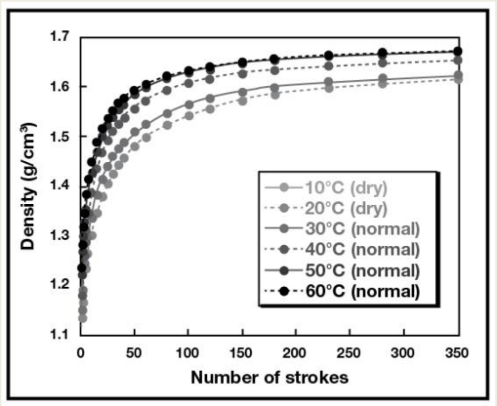


Figure 7. Rammability of paste, from SINTEF.

Machine Concept

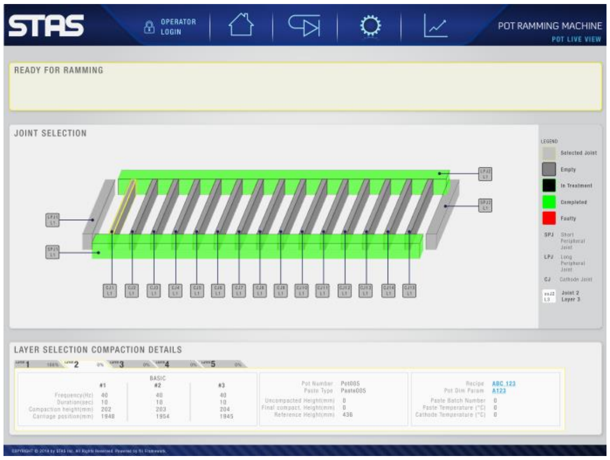
Putting together the results of the experimental work, and tying this up with the design objectives and the operational orientations desired at first, some technical challenges were foreseen and needed to be addressed. The concept of the machine was derived from these premises.

At first, it was defined that a true linear motion of the compaction device was the natural and most efficient way to compact the paste. This led to the design of an innovative *(patent pending)* ram featuring a fully vertical motion for compaction.

With this ram design concept it is possible to address the important challenge of noise control. Special attention was given to the design aspects of noise control as well as transmissibility of vibration, and a highly efficient, multi-layer concept for vibration isolation was developed to effectively uncouple the vibrating compactor from its supporting structure. Minimal vibration transmissibility and effective noise reduction were achieved. The final design has the ability to correctly isolate the vibration from the exciters to the remaining of the equipment, but it can also allow a slight misalignment between the compaction tool and the cathodes and protect the equipment in cases of mechanical collision.

Moreover, the ram design led to significant advantages in terms of ergonomics and operability. Its slim design offers maximum visibility and minimizes interference with operators' movements, while its extended stroke capability gives enough ground clearance to transfer the machine without an overhead crane. This last feature is a significant gain in EHS as well as a true gain in terms of overall efficiency, especially in greenfield operation where the availability of overhead cranes is limited. Furthermore, it even opens the door to flexibility in ramming parameters, allowing, for instance, the use of 200 mm risers over the cathode for a thicker last layer.

With regard to control and automation, there was a true need to bring pot ramming to the latest standard. Among these, there was a clear necessity to automate the recording of compaction data and develop the quality control operation as embedded. A dedicated PC with its own interface is used to collect and record the complete compaction profile of a pot and compare it to the predetermined production recipe and compaction quality criteria (Figure 8). With the built-in encoding devices, a complete mapping of the cell is performed, including the positions of the joints, the number of layers and the compaction levels. During the operation, the system automatically measures the compaction levels in real time, which activates an alarm if improper compaction is detected, thus avoiding the costly reconstruction of the cell if this problematic layer is detected too late in the process.



READY FOR RAMMING

	BASIC		
	#1	#2	#3
Frequency(Hz)	40	40	40
Duration(sec)	10	10	10
Compaction height(mm)	202	203	204
Carriage position(mm)	1948	1954	1945

Pot Number	Pot005
Paste Type	Paste005
Uncompacted Height(mm)	0
Final compact. Height(mm)	0
Reference Height(mm)	436

Recipe	ABC 123
Pot Dim Param	A123
Paste Batch Number	0
Paste Temperature (°C)	0
Cathode Temperature (°C)	0

Figure 8. Quality control HMI screenshot.

Full Scale Shop Trials

To complete the development work and offer a technological demonstration to the users, a full-scale, industrial-grade prototype was built. To actually measure and record a dynamic response in the most demanding configurations, the industrial prototype was built to fit the longest pots, from the newest 600 kA technology. Final compaction trials had to be as per an industrial pot configuration; thus, a real pot with partial cathode lining was used – however, for practical reasons, a smaller pot had to be used instead. Trials were conducted in a P155 shell, without refractory, with an assembly of 4 cathodes to simulate the pot end (Figure 9). It provided the ability to compact cathode joints, one small peripheral joint and a partial side peripheral joint. Cathodes were deposited on a layer of sand.

The joints were compacted following a typical P155 paste ramming procedure as used in a RTA plants. Again, the valuable support of AP experts was given for supervision and qualification. Compaction parameters such as vibration frequency, dynamic loading, static loading and time of compaction were set to the levels determined from our previous experimental work. Carbone Savoie S20 paste was used, preheated to 25°C. Bulk paste layers of approximately 150 mm were deposited into a P155 pot before each compaction. A total of 6 layers were necessary, the last one with a riser (Figure 10).

Figure 9. Full scale bench test with a P155 shell in the shop

Figure 10. Steel raiser used to make sure that the last layer finishes over the cathodes.

Results

In terms of compaction behavior, the industry standards and qualification criteria were met. The first analysis was the calculated compaction levels based on the heights of the measured layers after compaction. As per the procedures, the compaction level of cathode joints should be between 45% and 55%, with an average of at least 50%. The average compaction level was 50%. There was no compaction under 45%, and the standard deviation was less than 2%.

Cathodes were separated for further analysis of the compacted joints. Adherence to the cathodes was good. The hardness of the ramming paste was consistent, with no insufficiently densified area (Figure 11). The destruction of the joints showed that the layers bonding were good, without any over-compacted area on top of the layers (Figure 12).

From the dynamic point of view, the system fulfilled its promises in terms of vibration isolation and noise generation. The transmission of vibration was kept to very low levels, and the noise was measured below the recognized industry standard.

Furthermore, the equipment operability was proven very effective in terms of control and positioning of the tools, offering good precision and easy control. From the ergonomic point of view, the feedback from experienced operators in pot ramming machines is above expectations.

Figure 11. Compaction hardness and homogeneity.

Figure 12. A destructive analysis showed a very homogeneous compaction through the 6 layers, with good layers bonding.

Conclusion

The new Pot Ramming Machine is the result of a thorough development program.

Potential benefits through flexibility can be used with the same parameters as most plants use today, or the flexibility of the machine can benefit to a user willing to explore and potentially bring some cost savings.

This new Pot Ramming Machine has undergone successful testing both in-house and in a plant in Quebec, and it is now available for the industry (Figure 13).

Figure 13. Pot Ramming Machine.

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