Operational Advances in Melting and Holding Furnaces with In-Furnace Cameras and Laser Level Systems

Mark Bumford[1] and David Roth[2]
1. Sales Director, RIA Cast House Engineering GmbH, Leipzig, Germany
2. President, GPS Global Solutions, Downingtown, PA., USA
Corresponding author: mark.bumford@ria-che.com

Abstract

Significant advances in process control are now possible using air-cooled In-Furnace Smart Cameras and Laser Bath Height Measurement systems. These high-temperature resistant cameras allow for real time observations of scrap pile heights and shape, melting cycle progress, burner flame shape and colour and refractory damage monitoring. They provide a safe and real-time process development benefit that was in the past impossible to even observe let alone monitor, without opening the furnace door. New Laser Bath Height sensor techniques allow for accurate measurement of liquid metal volume enabling more accurate alloying additions and key measurements for metal casting volumes, assuring accurate billet or slab length from every cast. This paper will discuss the independent operation of these new tools and their potential integration to further enhance automated and fully autonomous RiA Furnace Charging and Skimming Machines.

Keywords: In-furnace cameras, Laser bath height measurement system, Furnace charging, Furnace skimming, Cast house automation.

1. Introduction

RIA Cast House Engineering GmbH is a supplier of capital equipment to the aluminum cast house, in particular furnace charging machines and furnace skimming machines. In recognizing the market desire to pursue Industry 4.0 and more relevantly Cast House 4.0 goals, RiA has integrated “Smart Cameras” within its machines to enable autonomous operation.

The very first implementation of camera technology was in the year 2014, as the result of a customer request. RiA was rebuilding a cast house in Germany and the client requested that cameras be installed in their furnace. Following some research, RiA found suitable cameras that had been implemented in glass furnaces by a German supplier called Fioscope GmbH. Those same cameras from that very first installation are still in operation today. The video images are relayed to a monitor located in the control room, from where the operators can visually monitor the progress of the melt and make decisions about when and what actions to take next.

It was a logical next step to add image processing capability to those images and to make the same decisions that the operators were making. By monitoring the height of the scrap pile, image processing can determine that the highest point in the pile would be below the charging machine container as it enters the furnace. This in turn could shorten cycles or ensure that there is no risk of the container failing to extend into the furnace due to contact with the scrap pile, or worse still, extending, fouling and then jamming in the furnace, leading to delays in the cycle and possible damage to the equipment.

After implementation of this technology with a couple of RiA Machines, numerous requests were received to install the “Smart Camera” system in other existing furnaces that were not served by RiA Machines. This led to this camera technology becoming a spin-off as a separate stand-alone package known as Furnace Monitoring Systems.

2. RiA Corporate History

RiA was founded under the banner of Rackwitz Industrieanlagen GmbH in 1997, by the former technical director of an aluminum plant that today belongs to the Hydro Group of companies. With experience in both cast house and downstream activities, RiA initially engineered and supplied solutions to both areas. In 2018, RiA took the decision to focus solely on the cast house and in particular with our key strength of furnace charging and furnace skimming machines. The company was rebranded as RIA Cast House Engineering GmbH to reflect this change.

In 2019, to support a growing US install base, RIA Cast House Engineering LLC was established in Indiana to ensure local service and support, including local stockholding of all major spares.

At the beginning of 2021, we formalized our relationship with Fioscope GmbH and signed an agreement allowing RiA to develop the furnace monitoring applications and offer those solutions worldwide exclusively to the aluminium cast house sector.

To date, RiA has supplied more than sixty-five furnace charging and skimming machines. All are rail-mounted precision machines, capable of charging up to 30 tonnes in less than 90 seconds or skimming a furnace faster than a traditional forklift truck or wheeled furnace tending vehicle, but with more repeatable results and without damaging the refractory lining. Key customers include Hydro and former Sapa, Constellium, Kaiser, Alumet, Matalco, and Ellwood. Many clients have multiple machines in the same cast house or across multiple sites and territories. One client alone has implemented more than twenty machines from RiA in ten different countries. Customer satisfaction is key to the nature of the repeat business that RiA has seen over the years.

3. The First In-Furnace Cameras

In 2014, RiA secured a contract to rebuild a cast house in Germany, including melting and holding furnaces, charging and skimming machines, an electromagnetic stirrer and a client-specific request to install cameras inside the melting furnace. The images from the cameras, mounted within the refractory lining of the furnace walls, were to be relayed to monitors inside a control room, located a safe distance away from the furnaces. The operators were expected to occasionally observe the monitors and make decisions about the progress of the cycle.

After some research, RiA selected Fioscope GmbH as the supplier of the cameras. Fioscope already had experience of installing the same camera hardware inside furnaces in the glass industry at higher application temperatures than those seen in the aluminium industry.

The project was a great success for all parties. The operators were able to observe the monitors at will, without the need to approach the furnace and open the door. All parties recognized that not only this offered the operators a new level of safety, but it also saved energy and shortened cycles by retaining heat in the furnace. Rather than relying on calculations of melt rates and weights of material loaded into the furnace or monitoring roof temperatures and gas consumption to determine when the melt was ready for the next step, the operators could simply glance at the video image on the monitor. Even the old method of prediction would have resulted in eventually having to open the door to verify. If they were too early, the door would be closed and the burners fired up to recover the roof temperature and complete the cycle, with time lost and more gas consumed. If the observation showed the melt was ready, the question still remained, how long ago it was ready. Every minute lost in the cycle is lost forever and can never be recovered. In addition, there is a potential risk of charging the next load into liquid aluminium, rather than onto a semi-solid or mushy layer of scrap. With the video images on the monitors, the operators were able to make the decisions of when to react, without opening the doors erroneously.

4. The Addition of Image Processing

The image is always available, but only of value when you physically look and observe the image. Very late one Friday during a nightshift, an explosion occurred inside the melting furnace. The cameras captured and recorded the build-up and the whole event. Figure 1 shows the images from the cameras. The first image is captured 15 seconds after the door was closed. The furnace had just been charged and the nearside burners were activated for the first time. The second image was captured 18 minutes later, one minute prior to the explosion. Bubbling and sub-surface movement can be seen, even in the still, to the bottom right corner of the middle sow.

Fortunately, nobody was injured and no equipment was damaged, but the force of the explosion was sufficient to flip a sow, weighing more than one tonne, 180 degrees landing on a different place from where it had started as seen in Figure 2. Liquid aluminium was sprayed throughout the inside of the furnace, but the cameras continued to operate. On playback of the footage, it was clearly evident that bubbling was visible and became more violent for a full 9 minutes prior to the explosion. It was clear that the operators did not observe the monitors in the final minutes before the explosion. This was not anticipated since they had not long before charged the furnace and were not expecting to take the next step for some time. However, the fact remains that the situation could have been far worse, potentially catastrophic, with loss of life and/or significant destruction of the cast house.

The incident raised many questions including the possible warning of the operators for a potentially unsafe situation. Then, actions could have been taken to minimize risk or even avert the potential incident. The next question was, if the cameras can help in making such decisions, what else they could reveal.

Figure 1. In-Furnace Camera stills. Left: 15 Seconds after charging/door closed. Right: 18 minutes after door closed.

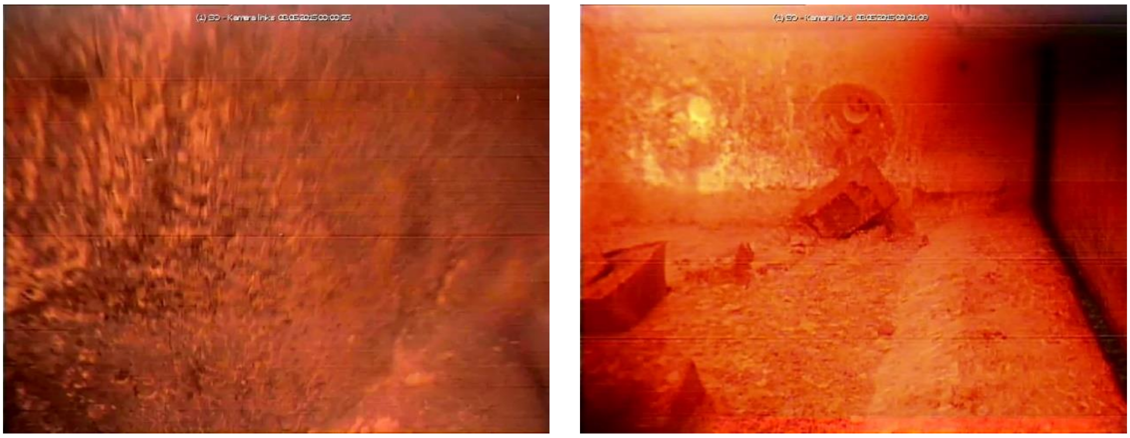

Figure 2. In-Furnace Camera stills. Left: Moment of explosion. Right: Sow physically moved.

5. The Integration of Smart Cameras and Furnace Tending Machines

Having moved beyond the concept of "visual only cameras" to "Image Processing and Machine Vision", RiA in conjunction with Fioscope began to develop capabilities to enhance the furnace skimming and furnace charging machines. The first capability was to determine that the scrap pile has melted down to a height that would not interfere with the container of the charging machine, as it enters the furnace as shown in Figure 3. This would allow calling for the next charge as soon as possible in the cycle and ensure that the next charge is distributed on a semi-solid layer of scrap from the previous charge, thus ensuring safety, shortening cycle times, and saving energy. The cameras provide the output signal to start the charging cycle and the charging machine will commence the cycle as long as the operators have completed the loading of the machine and released or cleared it for use. The machine autonomously moves in front of the desired furnace and when in position, it interacts with the furnace to open the door. On receipt of the signal that the door is open, the container is extended to around 70 % of the depth of the furnace and a pusher plate starts to push the scrap off the container. Once the pusher plate reaches a pre-set position, it stops and the container is retracted against the stationary plate, until the container is empty. It retracts from the furnace and closes the door, before returning to the loading position. The charging process takes between 60 and 90 seconds to evenly distribute up to 30 tonnes of material across the hearth. This minimizes door opening times, again shortens cycles and saves energy. The even distribution of the scrap in the furnace maximizes the scrap melt rates.

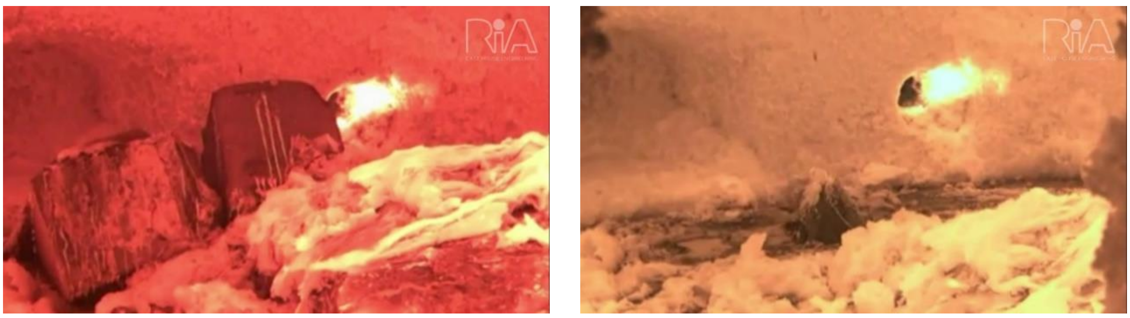

Figure 3. In-Furnace Camera stills. Left: Start of melt. Right: Ready for next charge.

Additionally, if the scrap pile melts at an uneven rate, due to different size and distribution of scrap in the charge, as is often the case, this can be detected by the cameras. This can be seen in Figure 4, where the scrap pile is concentrated on the left-hand side of the furnace. In cases like this, it would be beneficial to enter the furnace with a tool such as a skim blade and level the scrap pile, to spread the load and open up the center of the pile, exposing unmelted solids to the heat generated by the burners. This process also increases the surface area of the scrap pile. All of these factors lead to an increased melt rate.

Figure 4. Levelling an uneven scrap pile.

The next step was to consider the value of adding "Smart Cameras" to RiA Skimming Machines. These machines have been capable of automatic skimming for some years already. Through precise position sensing and position control, it is possible to follow a pre-determined skimming pattern, lane-by-lane, to remove the dross from the furnace, without contacting or damaging the refractory nor the need for an operator to be onboard the machine. However, it was observed that the machine would skim the entire surface of the bath regardless of the location of the dross, or if the dross were to move into an already clean and previously skimmed lane, the machine would not return and correct for this event. Effectively, the machine was blind. The solution was to install "Smart Cameras" on the skimming machine that have a clear view of the bath surface. The image in Figure 4 was actually captured by the onboard cameras. The cameras can identify the difference between dross and a clean surface as shown in Figure 5, and then drive the skim blade to the location of the dross and remove the dross from the furnace. Once again all of this is possible, without human interaction, other than to initiate the cycle. Even then, if the furnace contains RiA "Smart Cameras", they are capable of determining when the furnace has flat bath conditions and is ready to be skimmed.

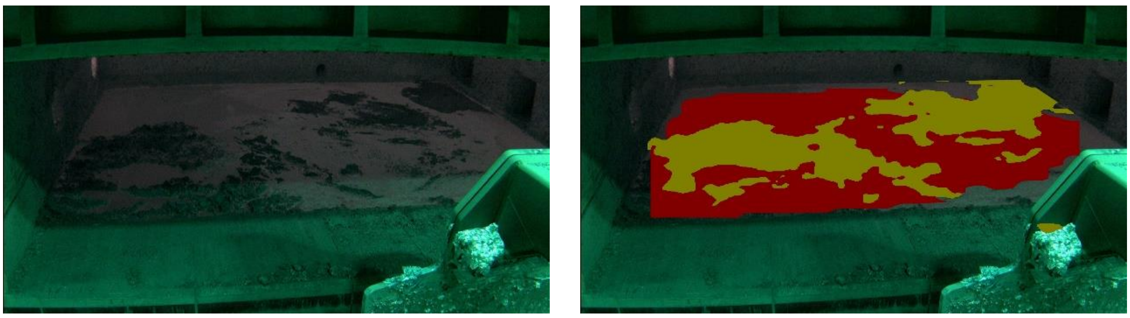

Figure 5. Skimming machine cameras. Left: Raw image. Right: Dross identification.

In addition to these capabilities, it also became clear that if part of the surface was already clean, time was saved by not skimming that lane or not extending the boom all of the way into the furnace. If dross moved during the skimming process, the cameras identified this and instructed the machine to return to the previously cleaned lane and remove the dross. This is clear in a video, but difficult to demonstrate with a still pictures.

Having established these key capabilities, all RiA "Charging and Skimming Machines", sold in recent years, were either sold with fully autonomous capability or were built in such a way that this capability could easily and modularly be added at a future date.

6. Laser Bath Height Measurement Systems

In parallel to the "Smart Camera" developments, RiA was asked to develop a solution to determine the liquid aluminium content of a tilting holding furnace. The furnace did not have load cells and the tried and tested method was to open the door and have the operator make a rough and unprecise estimate of the capacity. Such estimations would vary in accuracy and from one operator to another, sometimes by several tonnes.

The RiA solution was to mount an air-cooled laser to measure the distance to the bath surface (see Figure 6). By knowing the geometry of the internal surfaces of the refractory, a volume and hence capacity could be calculated. The laser was mounted on the furnace roof, thermally isolated from the heat of the furnace. The unit takes a measurement on demand, usually after skimming and just before casting commences. The accuracy in distance measurement of +/- 1 mm was sufficient to determine if it would be beneficial to cap-off one of the strands on the billet table and cast the remaining stands longer and not risk short-length rejects of the whole batch.

Figure 6. Laser bath height measurement system.

Additionally, it was found that, in primary cast houses, the accuracy of knowing the volume of the heel that remained in the melter-holder after casting affected the amount of alloying elements that would be added in the next cycle. By accurately knowing the volume of the starting heel, the correct volume of alloying elements can be added to supplement the liquid from the pot lines, meaning the specification of the final alloy could be met first time, without the need for further trimming and loss of time. This is also proving to be the case on secondary scrap remelt furnaces.

7. The Birth of Furnace Monitoring Systems

Having supplied a number of RiA machines with "Smart Cameras", more and more requests were received for cameras inside furnaces that were not served by RiA Machines. Additionally, new requests were arising for new features and capabilities that were unrelated to charging and skimming. The ability to monitor the burner flame, shape, colour, and length for example, to help with burner tuning or to alert to maintenance issues. Even the ability to monitor refractory damage, propagation of cracks or consistent bright spots, getting brighter or larger is possible. All of these and more are possible by passing known data through the Fioscope "Neural Network" that self learns what is correct and can then alert when something is anomalous, such as the very early example of bubbling liquid prior to the explosion, captured back in 2014.

Earlier this year, RiA packaged the Furnace Monitoring System into a stand-alone offering. It consists of typically two in-furnace cameras to monitor the melt status and one cast house camera mounted externally, with a view of the front of the furnace. A data collection, storage, and display centre is located in a control room. The package is complemented with the laser bath height measurement. The data collection centre is linked to the furnace controller as well as storing to the time-synchronized video images on a FIFO, receiving and storing data such as roof temperature and gas consumption. Full data video playback is available for a minimum of one hour from all cameras to cover unexpected events; and select frames are stored for time-lapse playback of longer-term trends such as refractory wear and damage. All data is time-stamped.

8. Conclusions

Smart Cameras systems can reduce unnecessary door openings, shortening cycles and saving energy. These systems can increase safety and potentially avert accidents. Smart Cameras systems also allow the melt cycle to be optimised, ensuring charging can take place at the first opportunity.

Laser Bath Height Measurement can reduce short-length batch rejects. These systems can accurately determine the volume of liquid heel leading to more first time "on specification" cycles. Furnace Monitoring Systems allow playback, trouble shooting and diagnostics. Cast House 4.0 is one step closer through the us Smart Cameras.

9. References

1. David Roth, Fully Automated Furnace Skimming and In-Furnace Dross Processing Increasing Production and Saving Cost, ICSOBA Virtual Conference Nov. 2020
2. Michael Rockstroh, Innovation in Charging and Skimming, International ALUMINUM Journal 2019, 7-8,
3. RIA Cast House Engineering, GmbH, Walter-Koehn-Str. 6A, 04356 Leipzig-Germany https://www.ria-che.com
4. Michael Rockstroh and David Roth, Verfahren und Einrichtung zum Entschlacken metallurgischer Schmelzen, Deutsche Patentanmeldung Nr. 10 2019 106 014.1.