Automation of Furnace Tending: ARFT Technology

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Abstract

With increasing aluminium production worldwide, both primary and secondary aluminium producers deal with repetitive and demanding furnace tending tasks. That added to the manpower shortage the industry is facing. Two equipment designers pooled their expertise to create a new state-of-the art equipment, Automated Robotic Furnace Tending (ARFT). It is not the first time that Dynamic Concept and EPIQ Machinery co-operate, but ARFT is their first co-creation meant to relieve aluminium producers from furnace tending operations still executed by operators.

Furnace tending is one of the activities in the casthouse which most depends on operators. Due to the large dimensions of melting and holding furnaces, the tending equipment is also large, either mobile and operated by people or mounted on rails. Robotics integration is limited because standard robots are designed for high speeds with small payloads while here slow speeds at large payloads are required. To overcome these limitations, a custom robot has been designed, integrating innovative features such as portability (onboard energy supply) and high payload capacity. The key elements of the complete system (*i.e.*, user interface, robot control system, and integrated vision system) for which the technology is patent pending were developed and manufactured by Dynamic Concept. EPIQ MECFOR contributed to the engineering and manufacturing of the components providing the mobility required for the equipment and the tools for working in molten aluminium.

This innovative, energy-efficient robot will automate furnace skimming, stirring, and dry cleaning with programmed and flexible operation. Through its geometry and its ability to produce different movement patterns, ARFT will improve the quality of furnace tending. It will cover the entire surface without omitting an area in less time. In addition, precise force control will help prevent refractory breakage. Battery-powered, ARFT will offer great adaptability to any environment and will have flexibility, thanks to the integration of an artificial vision system.

Keywords: Furnace tending, Automation of furnace tending, Artificial vision, Constancy of operation, Workforce optimization

1. Industry Commonly Encountered Issues with Furnace Tending

Furnace tending is one of the least automated activities in the casthouse. The size of the furnaces, their various geometries, the temperatures inside the furnaces as well as the general conditions of the immediate environment of the furnaces represent a significant challenge for the automation of tending operations. Nowadays, the general practice for furnaces with the capacity ranging from 10-20 tonnes up to 120 tonnes is to do loading using vehicles or dedicated charging machines and to carry out other activities such as mixing using electromagnetic stirrers or large vehicles fitted with long and cumbersome metallic attachments. Skimming and cleaning are other activities carried out using wheel-based vehicles or dedicated rail mounted equipment. In any case, fully automated movements are difficult, if not impossible, to achieve when using vehicles, which leads to many problems such as vehicle and furnace maintenance costs due to harsh operating conditions.

Equipment manufacturers are beginning to offer equipment that includes assistance to the operator; but, most tasks, especially furnace cleaning, still rely on an operator. We worked on the problem with an entirely automated (robotized) vision which we consider a new approach.

This project began with the intention of using an existing, commercially available robot to perform furnace tending operations. During the design phase, it became obvious that a specific custom design was required. After a few trials, a configuration was designed to adapt to the specific shape of aluminium melting and holding furnaces.

At this point, EPIQ Mecfor expertise was requested. Their engineering team is used to design demanding mechanically-articulated equipment. Known in the industry for its mobile equipment and solutions for loading and maintaining molten aluminum furnaces, EPIQ MECFOR contributed to the design engineering, energy needs studies to allow proper operations and manufacturing by guiding in the components selection, especially for the telescopic movements. Analyses on furnace tending operations were conducted in casthouses. EPIQ MECFOR also offered inputs and gave recommendations about the working principles and the safe operation of ARFT, making it highly reliable. This provided the required mobility for the equipment and the adequate force to the tools while working in liquid aluminium. Finally, EPIQ MECFOR supplied an extremely stable base on which ARFT could operate without any problems.

1.1. Manpower Availability

Demographics in the Western world make it increasingly difficult to recruit and retain manpower. The inverted age pyramid leads to more people leaving for retirement than young people entering the market. As a consequence, recruiting personnel – especially for physically demanding tasks, even with high-end salaries – has become increasingly difficult for aluminium casthouses.

This human resource problem puts pressure on operation and technical teams, which relies more and more on automation. The low hanging fruits having been harvested already, it is now time to look at more challenging applications such as furnace tending. This is also one of the driving forces for the implementation of automated guided vehicles (AGVs) for routine operations such as anode and metal hauling within the plant.

1.2. Other Driving Forces Behind Automation

One such driving force is the generally well-known fact that the variability of a process is reduced through automation; thus, automating furnace operations can help better control residual dross. There is also increased pressure in North American and European plants to reduce costs in order to compete with plants in BRIC countries. Robotization helps reduce production costs by improving productivity and consistency of operations as well as maintenance costs for furnace tending equipment and furnace refractories.

Another important driving force is safety. The use of a diesel-powered vehicle with hydraulics in front of a furnace exposes the worker to molten metal splashes if the tooling or charging alloys are not properly preheated. Although modern furnace tending equipment integrates excellent worker protection, there is always a risk of fire in the event of metal projections or spillage.

The interaction between vehicles and pedestrians is also one important risk factor in the casthouse. Many efforts are made to prevent pedestrians and vehicles from passing each other, but certain interactions are sometimes difficult to avoid.

1.3. Existing Technologies for Furnace Tending and their Limitations

- **Vehicles**

The simplest equipment for furnace tending is a specialized and extremely flexible vehicle used to perform many tasks such as charging, alloying, mixing, skimming, and cleaning of the furnace. However, the downside in using vehicles is that, in all cases, they require skilled operators; therefore, with the limitations that this implies such as schedules, breaks, meals, intershift delays, the operating window is reduced. In addition, skill variability between operators, including skill reduction due to fatigue, reduces the efficiency of operations and increases maintenance costs. Tending operations are hard on trucks and increase fleet upkeep costs.

When using a vehicle, it is very difficult for an operator to accurately control the depth of the skimming tool or the force to be applied against the lining during cleaning. The long tool attachments that are used with these vehicles can easily hit and damage the furnace refractory lining and the roof.

Diesel powered vehicles also pose a health risk due to the possible build-up of carbon monoxide and exhaust gases if the area is not properly ventilated. Efforts are being made to electrify these vehicles, but they are still in the early phases of implementation.

- **Specialized machines**

Specialized machines, such as those used for charging and skimming for example, are highly efficient due to their specific technology. Most of the time, however, such specialization is limited to furnaces that are aligned so that rails can be used to displace the machines. Moreover, the furnaces, to be serviceable with the same tending equipment, must be identical or very similar. More specialized operations such as furnace cleaning still require human intervention with more specialized tooling (and still need a vehicle).

1.4. The Common Limitation: The Human Factor

The common limitation regarding existing technologies is the human factor. Since furnace operations are in the critical path for delivering metal to the casting equipment, casthouse managers wish to avoid anything that can disrupt the flow of metal, including delays in furnace operations. When operators perform operations that are in the critical path, this adds pressure to all casthouse operations.

In summary, manpower availability is becoming an issue in most of the Western world while furnace tending operations still largely depend on the skills of the operators. This is an important factor motivating the implementation of automated furnace-tending operations. However, various challenges posed by the furnace geometry and the casthouse configuration make it an opportunity for robotization compared to conventional automation.

1.5. Summary of Current Issues

- Furnace structure and refractory breaking
- Cleaning operation not on regular schedule
- Efficiency of cleaning
- Efficiency of stirring
- Personal turnover
- Safety

2. Technical Description of ARFT

The solution is a flexible, fully programmable automated Robot for Multi-Operation. A commercially available robot, even the biggest one, cannot cover the entire furnace area. These robots are designed for high speeds with small payloads while here slow speeds at large payloads are required. To overcome these limitations, a custom robot has been designed, integrating innovative features such as portability (onboard energy supply) and high payload capacity.

This robot has been tested under real conditions in operation many times and is now ready for implementation. A picture of the robot is shown in Figure 1.

It reaches all zones inside the furnace from one stationary position. Fully programmable with robotic algorithms for tending operation:

- Skimming
- Stirring
- Cleaning
- Others: Alloying, sampling, etc.

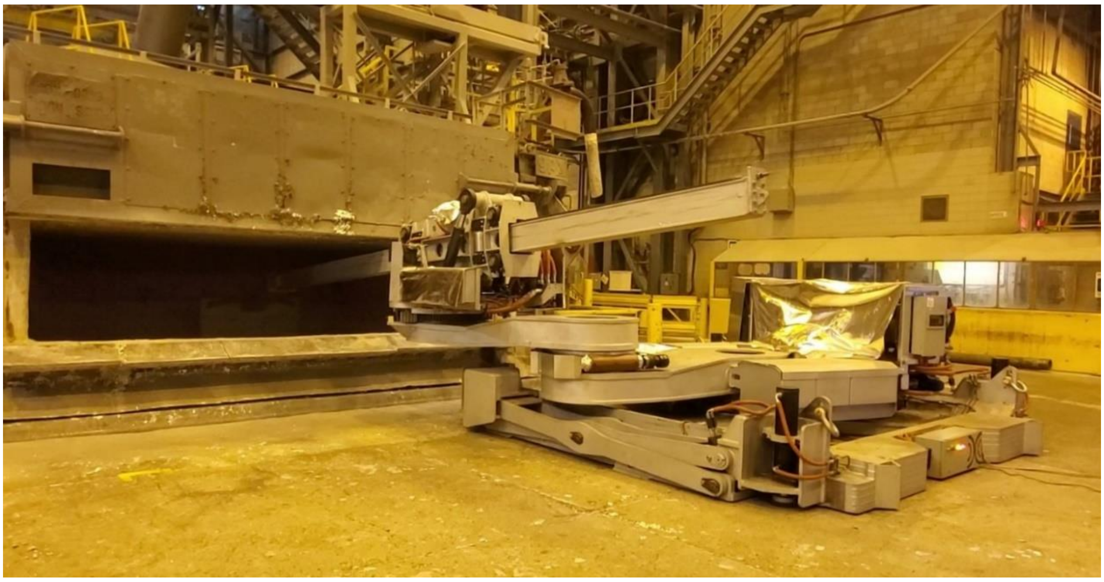

Figure 1. ARFT positioned in front of a furnace.

2.1. Mobility/Transportation Options

The robotic solution has been designed to fit many mobility options according to the desired automation level.

The options are:

- AGV: Auto-Guided Vehicle: Automated moving and positioning with AGV in front of the specific furnace to operate.
  - EPIQ AGV designed crucible hauler is compatible (see Figure 2)
  - AGV can handle other platforms next to the robot during operation
- Rails (see Figure 3)
- Remote controlled trolley
- Dedicated vehicle.

Figure 2. ARFT transported by EPIQ AGV hauler

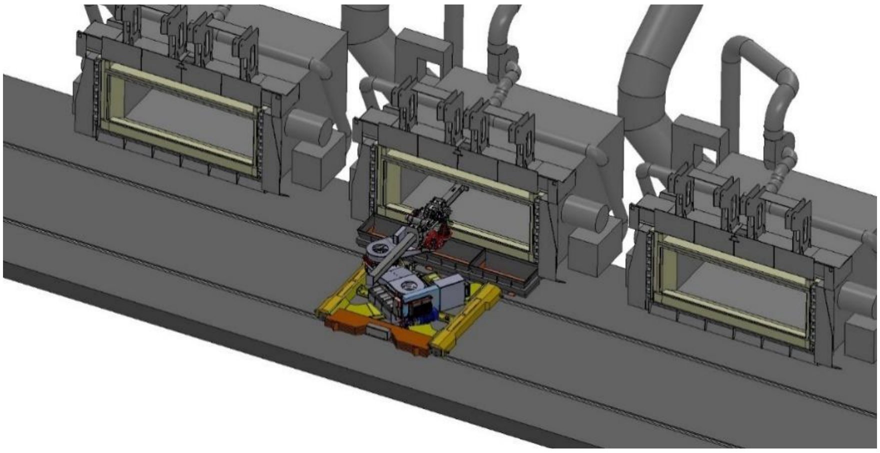

Figure 3. ARFT on rails for lateral displacements

2.2. Power

The chosen solution for power is battery to remove any constraints due to mobility. The features are:

- Electric powered
- Battery pack similar to the EPIQ AGV
- Auto recharging.

2.3. Vision System

To increase the efficiency of the operation, a vision system has been developed and integrated (see Figure 4). This vision system can:

- Monitor dross location
- Evaluate dross efficiency
- Other operating assistance
- Location of walls, door opening, metal level for robot operation
- Mapping of dross to remove
- Quality inspection of skimming

- Fine tuning of skimming
- Tools location feedback / confirmation inside furnace.

It is specifically developed for vision inside melting and casting furnaces. A clear mapping of dross over aluminum bath and furnace structure and inside walls are clearly detected.

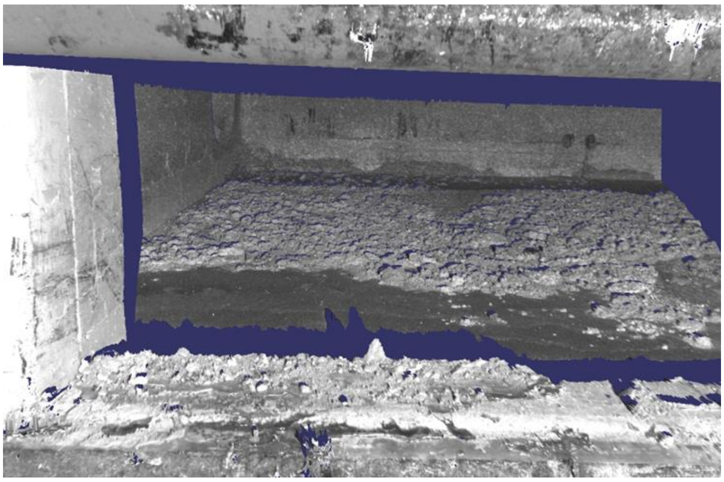

Figure 4. View in the lenses of the vision system.

3. Operating Mode and Results

Real robotic solution allows full control on movement, position, speed and applied force. Depending of the operation tasked, all parameters are programmed to give the best efficiency under any circumstances (see Figure 5).

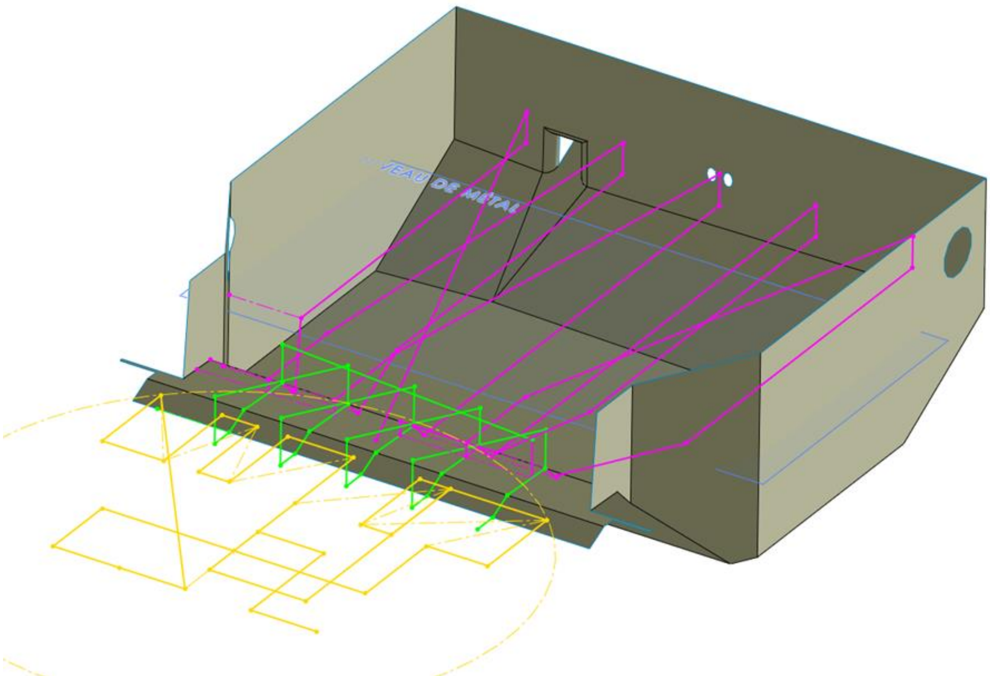

Figure 5. Programmable movement pattern based on the task to be done.

3.1. Skimming

The system is programmed to cover all surfaces with accurate positioning of the tool. Since the metal level is measured, the penetration of the tool inside the metal can be adjusted to minimize metal pick-up. Also, the vision system allows a quality control check to locate and remove any remaining dross.

3.2. Mixing

The path of the tool can be programmed to optimize mixing. For example, the tool can do circular or figure eight movements at various depths in the metal. The tool can also reach the floor of the furnace along the course of its path, ensuring proper mixing of heavier alloying elements that tend to sink to the bottom. This results in a highly homogeneous alloy mix.

3.3. Cleaning

A big advantage of the ARFT system is the capability to control the applied force. Combined to the capability to reach all walls and bottom, the cleaning task is very efficient.

The tool applies a controlled force onto the wall for cleaning which allows the removal of dirt without breaking the refractory.

Furthermore, since the operation is automated, cleaning tasks can be performed at a higher frequency to avoid the build-up on the walls and at the bottom.

3.4. Alloying and Other Operations

The technology allows automated operation of alloy charging into the furnace as well as the dross pan handling. The flexibility of robotics offers many options to automate complementary tasks.

4. Conclusion

One of the greatest challenges in casthouse automation is the tending operations of the furnaces. Large areas to cover, heavy loads, varying furnace configurations, and harsh conditions make it difficult to implement automated solutions. In addition, manual operations with heavy vehicles require a skilled workforce that is increasingly difficult to recruit and retain. This is why it is desirable to come up with robotics solutions that can overcome the challenges while providing the flexibility of human-operated equipment.

The robot is now in the trial phase and should be in full operation shortly, by the end of 2022.