Application of technology to improve safety at the EAF, by eliminating human operation

The steel melting process in an electric arc furnace (EAF) is a complex set of tasks, coping with highly dangerous hazards as fire, explosions, uncontrolled reactions, hot metal projections, and gas or dust emissions. Melt shops are dangerous working areas for operators, recording statistics with a high frequency of injuries. This article describes the available technological packages to eliminate the staffed activities on the melting floor, with the aim to prevent accidents and keep furnace operators safe.

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Fig 1 **Slag door clearing operations**

Fig 2 **Operators taking a sample or a probe**

INTRODUCTION

Continuous efforts to optimize operating costs and enhance plant performance in terms of productivity, have resulted in modern steel shops with shorter tap to tap times. The electric arc furnace (EAF) has progressively transformed into a complex metallurgical reactor, with several concurrent operations taking place. Specific technologies have been developed and introduced over the years, under the comprehensive supervision of sophisticated and reliable control systems. These systems have made possible the application of ultra-high electric power and facilitated a progressive increase in the input proportion of chemical energy to the furnace and the melting rate. However, the operations involved in the melting process still require that some tasks are performed manually. Steel sampling, clearing the area around the slag door, tap hole cleaning and sanding are recuring operations that require skilled personnel to be fulfilled. Regardless of all the best training and personal protective equipment, there is exposure to serious risk, and statistics report that severe injuries and fatalities still occur.

MORE has been dedicated to the design of specialized equipment to replace the staffed operations in melt shops for more than 20 years. The company works side by side with steelmakers, supporting their need for reliable automatic tools, to remotely control EAF operations in the shortest possible timescale. This process of continuous improvement has generated a complete suite of proven, mature solutions, enabling personnel to fulfil all the required operations safely and reliably, from the control room.

RECURRING OPERATIONS

Some operations are required at each EAF cycle, such as clearing the area around the slag door, taking a steel sample, probing the melt temperature, inspecting the tap

hole after tapping and sanding. These activities consume time and expose operators to severe risk of injuries. Operations at the door (*Figure 1*) are prone to sudden reactions that occur rarely, but are highly unpredictable.

In some steel shops, company safety rules require that it is compulsory to switch the electrical power off prior to approaching the furnace floor. In a few countries this is also prescribed by law. Switching the electrical power off is of course time consuming and interrupts melting but, above all, it retards the foaming slag process, which takes time to rebuild again. In most steel shops, it is common practice to allow personnel to operate at the slag door with the power on, for instance to take a sample (*Figure 2*). If there is a boil reaction, or a sudden blast, any workers close to the furnace are exposed to severe injuries, regardless of the safety equipment they are wearing.

Tapping operations may be regarded as the most critical in the overall furnace cycle. In less than 3 minutes, more than 100t of liquid steel at a temperature higher than 1,630°C, is transferred into the ladle by a stream travelling as fast as 5m/s. Normally, when the gate for Eccentric Bottom Tapping (EBT) swings away, the stream opens freely and tapping operations can start immediately. Sometimes the stream does not open spontaneously. In these cases, the tap hole requires oxygen lancing to clear any clogging. In such an unlikely event, a skilled operator must approach the EBT gate area from the bottom with a bent pipe, to lance the taphole and clear it from few meters distance, using oxygen (*Figure 3*).

At the sump area, after tapping operations, the tap hole needs to be inspected, eventually cleared of slag residuals and filled in with sand. This operation requires an operator to walk to the EBT balcony to perform the required actions (*Figure 4*).

Where melting is incomplete, residual materials and skulls may fall in the area, obstructing the tap hole sleeves. Efforts to remove the obstructions can sometimes be difficult to fix and time consuming. All of these operations entail unpredictable time losses and exhausting manual labour in hazardous conditions, such as restricted space, heat, dust, hot sparks, ejections from the furnace and operating with oxygen. These hazards pose a high risk of injuries and higher production costs.

SLAG DOOR SILL CLEARING: MOTANK

Maintaining the slag door's sill area and keeping it clear of scrap, or skull build up, is very important for the efficiency of the steelmaking process. Performing these operations during the arc melting is beneficial for production throughput and also improves the effectiveness of the cleaning action and the metallurgical process. MOTANK (*Figure 5*) is a remote-controlled ram, specifically designed to operate at the slag door. The carriage moves independently on rails, which can be arranged along the axis of the slag door, or perpendicular ▷

Fig 3 **Operator lancing the taphole**

Fig 4 **Operator at EBT balcony**

Fig 5 **MOTANK**

Fig 6 **CATFIS**

Fig 7 **Automatic cardboard sample tube changer**

Fig 8 **CATFIS 2.1**

to the door, to best fit in almost any layout, even where the EAF is encapsulated in a doghouse. The ram is actuated by an onboard hydraulic cylinder. The pulling force is designed to easily clear scrap and skull in all the situations. It can be also tilted downwards to better fulfil the clearing action.

The MOTANK operating cycle starts automatically under the supervision of the melter from the control room. Clearing operations are performed during the power-on time in a reliable and predictable way, without interfering with the melting practices. By exception, the operator may remotely control the ram functions by direct commands. Once the clearing operation is completed, the MOTANK automatically deploys to a parking position, further from the furnace. Any maintenance, or check takes place in the parking position.

In quality steel mills, the MOTANK proved itself as a very effective tool for dephosphorization purposes. Early deslagging plays a key role in the metallurgical process. Clearing of the sill around the slag door is coordinated to the appropriate time and in tandem with the slag foaming practice. It is automatically started by the melt profile and is performed promptly and on time, thanks to the extremely reliable pulling force. As an example, consistent dephosphorization results, with concentrations lower than 80ppm, have been achieved in the production of rail wheel grades after installing this technology.

The proven reliability of the MOTANK in clearing the slag door gives further benefits and operational advantages in other functions, such as improving the safety and reliability of sampling and probing, removing the requirement for sill cleaning during turnaround and eliminating the need to use dolomite on the sill, as residual, frozen, soft foam slag protect this area.

AUTOMATIC SAMPLING: CATFIS

The first EAF sampling manipulator installed by MORE dates back to 1997. Over the years, the equipment, known as CATFIS, has evolved to a mature state that has been optimized in great detail (*Figure 6*).

The manipulator has a swinging movement around two axes of rotation, such that it can approach from the initial parking position to the measuring position. The terminal arm is water cooled to guarantee a long life and proper protection for the cabling and measuring lance sensor. All of the mechanical components are carefully shielded from heat and slag radiation by metallic protection. Once in the measuring position, a linear actuator inserts the lance into the bath, along a calibrated curved trajectory. To perform a reliable measurement, the lance insertion movement is controlled for both speed and position. If a collision is detected, the manipulator automatically retracts the lance to avoid further damage. The insertion depth can be varied according to steel bath level and refractory wear. This functionality is very useful,

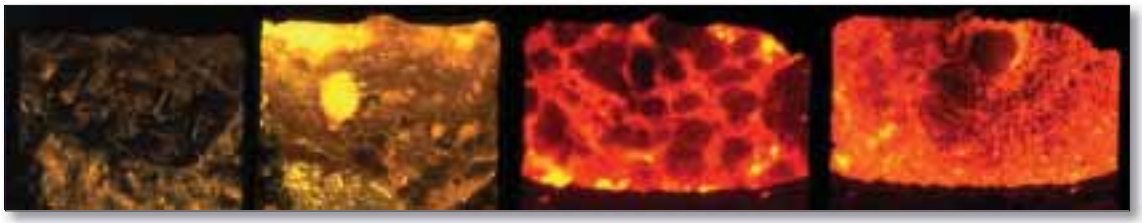

Fig 9 **EBT EYE imaging, showing L to R: charge scrap, start melting, start tapping and end tapping**

particularly when applied to continuously fed furnaces, operating at flat bath conditions and facing a wide span of the bath level. The CATFIS manipulator is designed to move to a parking position far from the furnace, where the operator can change the cardboard sample tube in a safe and protected way. For EAFs surrounded by a doghouse enclosure, the parking position is designed in such a way that the lance fits through an opening and the carboard sampling tube can be changed from outside the enclosure.

The current focus for further enhancing operator safety during sampling, is to provide an automatic changing device for the cardboard sampling tube. Many suppliers have proposed different solutions. However, the availability and reliability of the equipment is still low, requiring frequent intervention by maintenance personnel. The operation to replace the cardboard sample tube, which a man can easily perform in few seconds, is a complex task for automation.This is due mainly to deviations of the lance from a nominal position and subsequent misalignment. The engineering team has thoroughly analyzed the failure modes of existing systems and defined the required functions for an automatic cardboard sample tube changer that will eliminate, or work around, failure points. This analysis highlighted that cleanness, flexibility and a larger fitting tolerance are the key aspects for a reliable, mechanical operation. A brand new design concept has been developed and is being applied as part of the package on existing CATFIS equipment and CATFIS 2.1 manipulators (*Figure 7*).

The process of substituting mechanical actuators with electrical motors with drive control is a continuing trend to simplify equipment, increase flexibility and improve control management. A multiple axis manipulator (*Figure 8*) has been already designed and is in operation in several melt shops.

The multiple axis manipulator has the following advantages: flexibility and compactness for fitting into constrained and confined areas, total control of movement and adapting trajectories, easy maintenance, automatic cardboard sample tube change, tailor-made for harsh, steelmaking environments and capable of multi-tasking operations.

Fig 10 **EBT-SAND (on board version)**

Fig 11 **AUTOSAND (off board version)**

TAPHOLE INSPECTION AND SANDING: EBT EYE, EBT SAND, AUTO-SAND

In addition to the slag door area already mentioned, another challenge for operators is maintenance of the EAF sump area and operations both during and after tapping, where a visual inspection of the tap hole is commonly made. To automate these processes, the greatest issues to address centred on the installation of sophisticated electronic equipment and keeping optics clean, as well as having the correct exposure and frame rate to obtain clear, high resolution images, in highly variable illumination conditions. A long process of optimization, involving many engineering competencies, brought about the solution: EBT EYE. This is an integrated package adopting the highest standard state of the art digital cameras, with proprietary vision firmware to enhance the dynamic response and resolution of the imaging, in all EAF operating conditions (*Figure 9*).

The EBT EYE installation has demonstrated a high standard of availability, image quality and remote vision and requires ▷

Fig 12 **STAP manipulator**

Fig 13 **STROP in operation on an EAF in Mexico**

only periodical routine checks. EBT EYE works in tandem with the automatic sanding equipment, EBT SAND. Different solutions have been developed and installed to obtain the best results in terms of layout fitting and reliability. The 'on-board' solution (*Figure 10*) is a compact all-in-one design, assembled on a sliding guide. A local small bin delivers the correct amount of sand via a small, stationary dispenser, located close to the furnace. The EBT EYE is mounted parallel to the feeding chute to check the taphole status and that feeding is correct in real time.

The whole sequence for tap-hole turnaround completes in less than 30s on average. The operator can start it immediately after the furnace tilts back and they can level the furnace immediately afterwards. Where there is clogging that requires lance cleaning, the entire system can be moved into the park position, eliminating any interference for access to the sump area. After completion of the operation, the EBT window is covered to avoid flaming, slag overflow, or hot metal ejections during scrap loading and melting. The on-board version is particularly suited to flat bath operation, where the roof is rarely opened over the sump area.

Another version of the equipment, AUTOSAND, has been developed specifically for 'off-board' installation (*Figure 11*). Installation of the equipment far from the furnace enhances system reliability and reduces maintenance. Where there is a frequent shell change practice, only one system is required.

TAPHOLE LANCING: STAP

The STAP manipulator is a multi-axis piece of equipment, dedicated to lancing the tap hole, where there is clogging (*Figure 12*). The equipment is normally parked offline and armed with a special pipe, ready for use.

Where the tap hole fails to open, the operator can start the cycle from the control room and the STAP automatically inserts the lance into the tap hole. To centre the sleeves, the extension of the device is adjusted according to the platform tilt angle. Once the lance is in the correct position, oxygen lancing starts, together with the vertical movement.

The STAP device is only used when required. Nevertheless, it saves a lot of long delays that usually accumulate in steel shops, due to the time required for operators to prepare when there is a failure to open. The main benefit of this application is however its safety advantages.

TAPHOLE CLEARING: STROP

Solid scrap, skulls or heavy residuals may obstruct the tap hole after tapping, precluding the possibility to correctly fill the sand. Sometimes obstructions are drilled by the operators by oxy-cutting. Lancing is not effective in slag skulls, concrete or graphite blocks. These tasks, although not carried out very often, normally generate long delays, sometimes hours. Production losses and costs associated with such incidents, plus damage to the sump panels and the risk of injury for the operator, are a very serious issue. The STROP is hydraulically actuated equipment that inserts a sturdy rod into the tap hole and can lift heavy loads, freeing the tap hole from any kind of obstruction (*Figure 13*).

CONCLUSION

It is now possible to integrate productivity and safety with the adoption of effective technological packages to fulfill all recurrent operations in the EAF melting cycle automatically. MORE provides for the reliable and functional design of equipment, which offers practical and effective solutions in several steel shops, shrinking the power-off time to a few minutes. Automatic slag door clearing, sampling and probing by a remote controlled manipulator, tap hole inspection and sanding are all well-established state of the art tools for MORE customers. Newly developed technology has proven to be very effective for reducing delays in the case of accidental clogging of the EBT. The manipulators STAP, for EBT lancing and STROP, for tap hole mechanical unclogging, proved effective in reducing delays in their first pioneering installations. The continuous effort of the designers and technicians at MORE to improve safety and productivity, is currently focusing on further integration of additional functions. MS

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