Electromagnetic slag detection system stabilizes furnace slag carryover and improves effective secondary metallurgy at Höganäs Atomizing Plant in Halmstad

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INTRODUCTION

Höganäs AB is a Swedish multi-national company which is the world's largest producer of metal powders. The company is a technology leader within its field and has 1400 customers in 65 countries with more than 1500 products, mostly customer specific, from 14 production centres situated in all main continents. The company's products are found in a series of application areas from structural components, to the automotive industry, to metal surface coatings and iron fortification of food. The main Höganäs iron powder production plant in Europe is the Atomizing Plant in Halmstad, which is situated on the western coast of Sweden.

Höganäs Atomizing Plant in Halmstad

The production of metal powders starts by the conventional electric steelmaking production route where carefully selected steel scrap, sponge iron and slag former additions, are melted in a 50 ton capacity electric arc furnace. After melting and refining the steel is ready to be tapped into the ladle via an eccentric bottom tap-hole (EBT) arrangement. It is desired that the molten metal is teemed slag-free into a ladle in order to promote further refining in the ladle furnace where temperature and composition is fine-tuned. When target composition and temperature are fulfilled the metal is transferred to the atomizing area where a fine metal powder is produced using water atomization technology.

Höganäs Atomizing Plant in Halmstad is a valuable customer of AGELLIS Group AB, successfully running several AGELLIS systems in their production, and after several discussions on how to further increase product quality and meet future customer requirements, furnace slag tapping was put on the table. A reliable method for furnace slag detection was identified as an operation with the most potential to fulfil these objectives. It was decided to run a test of the AGELLIS Group AB EMLI-SIF furnace slag detection system in order to minimize slag carry over and its effect on downstream processing.

The Agellis EMLI systems are designed specifically for the measurement of molten metal levels and slag indication during molten metal production. The EMLI-SIF system is based on electromagnetic principles and the sensors used consist of two coils mounted on each side of the furnace tap-hole.

The advantage of this technology is that it detects the onset of slag very reliably throughout the entire tapping process, thus providing operators with correct information to prevent transferring too much slag to the ladle. As the system is not affected by dust and flames, nor requires the presence of a free line of sight, it is able to assist the operator throughout the tap to maintain a correct tilt angle by warning at all times when slag is being pulled through the tap-hole.

The purpose of the trial was to identify whether the onset of slag during steel tapping can be detected in this specific production case and then to quantify the benefits of an improved and reliable detection.

The expected outcome is that the improved slag detection will result in a reduced and more uniform quantity of slag being tapped into the ladle, which is expected to increase production process stability with less need for late adjustments to the steel. This in turn results in lower production costs and consistent high product quality.

TRIAL INSTALLATION

System Installation
The EMLI-SIF system sensors were installed around the tap hole in the EAF with the aim to control the amount of slag that is carried over from the EAF to the ladle.
The EMLI-SIF sensors shown in **Figure 1** are designed for long-time operation in the conditions found in the refractory brick area close to the tapping stream. The sensors can operate in temperatures well above 600 degrees Celsius and require no cooling.

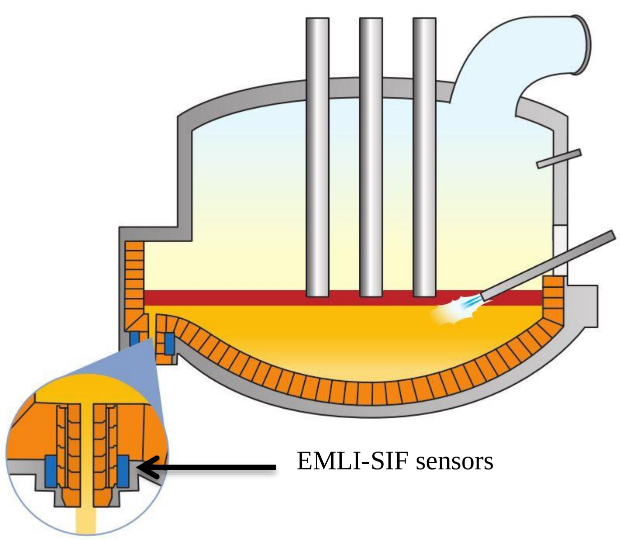

Figure 1 EMLI-SIF Sensor position on two sides of the tap hole

Systems Principal

A magnetic field is created between the sensors around the tap-hole. By monitoring the field and precisely measuring the changes in the field occurring when different amounts of steel and slag passes through, the EMLI-SIF system is able to discern steel from slag and warn operators.

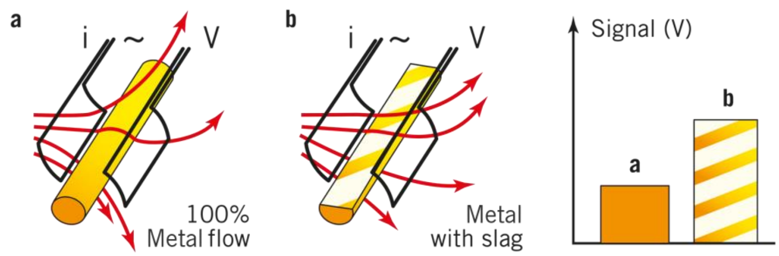

Figure 2 EMLI-SIF illustration of principal

System Connections and Layout

The different units of the system are connected as shown in **Figure 3**.

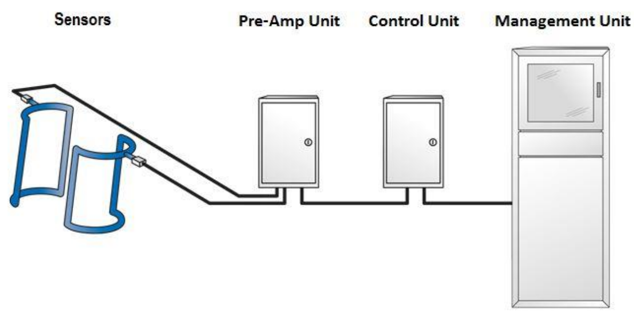

Figure 3 EMLI-SIF Electronics

The following components were used in the trial set-up; management unit, control unit, pre-amplifier, **junction** boxes and sensors, **Figure 4**.

The Management Unit (MU) is an industrial PC used to set up the system, store log files, remotely access the system and is usually placed in the furnace control room or nearby electrical room. The Control Unit (CU) which contains the autonomous measurement electronics of the EMLI-SIF system can be placed in an area close to the melt shop floor or in an electrical room. The Preamplifier Unit (PU) is placed within 20 meters of the sensors. The junction boxes, mounted on the side of the furnace, are used to provide an easy access contact point with the sensor leads. The sensors are placed inside the furnace refractories surrounding the tap-hole.

All EMLI components are developed to withstand the harsh environment in metals production and are installed in IP66 rated casings.

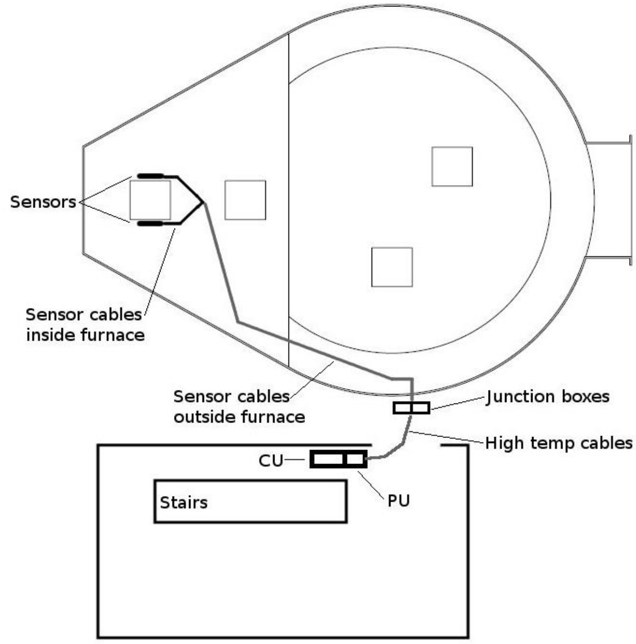

Figure 4 Installation layout

Signal Interface for the trial

The signal interface between the EMLI-SIF system and the plant PLC is composed of the following signals:

- Digital Input to EMLI-SIF: Tap is about to begin. This signal sets the EMLI-SIF to an active state.
- Digital Output from EMLI-SIF: Slag alarm. This signal activates when the system has detected slag.

For practical reasons no operator panel was installed as all relevant signals were sent directly to the plants PLC.

METHODOLOGY

Hypothesis

The trial evaluation is based on the hypothesis that heats tapped with larger amounts of slag from the EAF are negatively affecting the following process steps. Selected elements in the slag are expected, to some extent, to revert back to the steel. This will lead to prolonged processing time, demanding additional adjustments and ultimately affecting product quality.

Evaluation

Evaluation of the effect of slag detection during furnace tapping was performed by comparison of heat data from the Atomizing Plant in Halmstad production database with the EMLI system signals.

The following data was studied in the analysis:

- Signal from the EMLI system.
- Selected signals from the electric arc furnace; tilt angle, auto-tap, ladle weight etc.
- Steel chemical analysis from the electric arc furnace and ladle furnace.
- Temperature measurements, time, additives and other process events at the ladle furnace.
- General observations of processing on-site.

Limitations

The study was performed on a full tap-hole refractory campaign during the period October 31st to November 26th, 2014. Only steel grades A100BC and A100SH were included in the study. The total trial analysis involved about 220 heats.

Filtration of heat population

Only heats with a content of silicon (Si) below 0,003 %Si sampled in the LF where considered in the study in order to eliminate the influence of Si on the oxygen potential. Heats that where tapped without keeping a hot heel (“furnace emptying”) were also excluded.

Used indicators
Elements that oxidized during melting in the electric arc furnace and refined to slag, such as phosphorus, are separated from the process if no furnace slag is allowed to flow into the ladle at tapping. However, when tapping takes place, there will be some phosphorus present in whatever slag has been tapped and at the ladle furnace this is expected to reduce back into the steel. Phosphorus should therefore be a reasonable indicator of the quantity of slag tapped from the electric arc furnace (with a small allowance for the relatively similar oxidation ratio in the two furnaces).

From samples taken from the ladle furnace and the electric arc furnace it was concluded that there is a clear correlation between the % of phosphorus (P) and the % manganese (Mn) between heats which supports the hypothesis that the slag-metal reactions expected to occur also are reflected in a change of steel chemical analysis.

Evaluation of the element sulphur (S) was performed to confirm if the system slag-metal reactions are close to chemical equilibrium. The difference between the change in the sulphur content between the electric arc furnace and ladle furnace suggests that the system is close to equilibrium in the process.

Consequently, the indicative parameters used were the manganese (Mn) and phosphorous (P) reversion in the ladle furnace. When studying the difference in %P and %Mn between the two furnaces an increased content in the ladle furnace may indicate a slag tapping.

SIGNAL EVALUATION

EMLI slag detection
The EMLI-SIF signal monitors the electromagnetic field in a localised area of the tapping stream and can thus determine when a full stream of steel is replaced by a combination of steel and slag. Depending on the tapping procedures, the signal response will vary, directly representing the presence of steel in the tap-hole. The signal shape and trend are analysed by the EMLI system to warn for slag tapping occurrences. Three typical signal trends are shown below:

i) A normal tapping with very limited slag transfer,
ii) a tapping with slag transfer approximately half-way through the tapping, and
iii) a tapping with slag transfer at the end of the tap.

Figure 5 below shows a typical tapping sequence and the various signals that are logged by the system and used for evaluation.

A high EMLI signal means that there is no steel present in the tap-hole. When tapping begins and liquid steel fills up the tap hole the signal drops rapidly to a lower position. Thereafter, as any residual sand is flushed away and the refractory heats up the signal continues to drop gradually for some time.
As steel in the tapping stream begins to be replaced by slag the signal value rises, at first gradually as small amounts of slag enter the stream and then steeply as the steel is replaced by slag. When tapping stops the steel is no longer filling the tap hole and the signal returns to its high level.

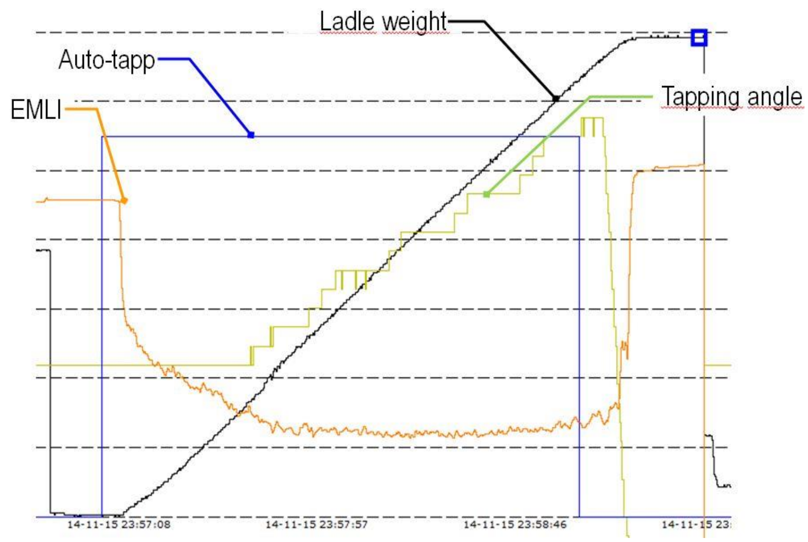

Figure 5 Signals recorded during tapping: (Heat No. 143900)

Figure 6 below shows a typical response for a mid-tapping slag detection represented by an EMLI-signal spike present after approximately two thirds of the tapping. This is likely to have been caused by a small amount of slag passing through the tap hole due to a low tilt angle of the furnace. Once the furnace tilting is increased, the signal drops again.

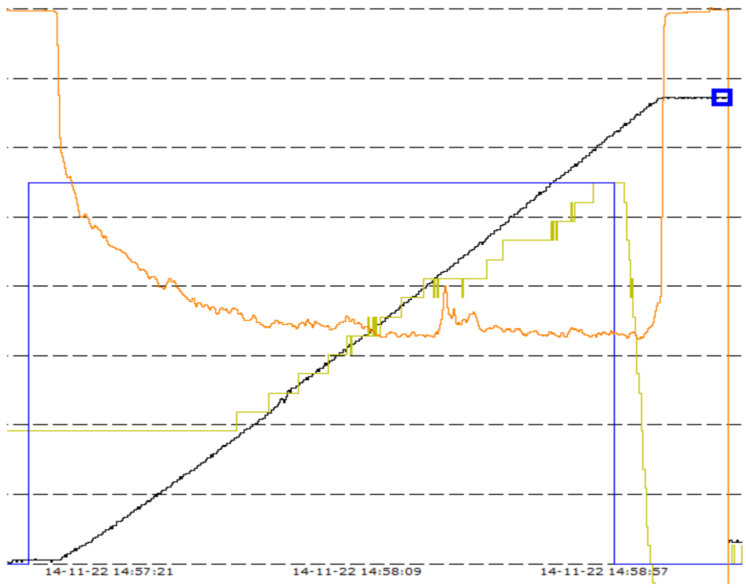

Figure 6 Tapping with slag entrainment midway

In **Figure 7** a slag detection found at the end of the tapping is indicated by the sudden rise in the EMLI-signal caused by entrained slag in the tapping stream.

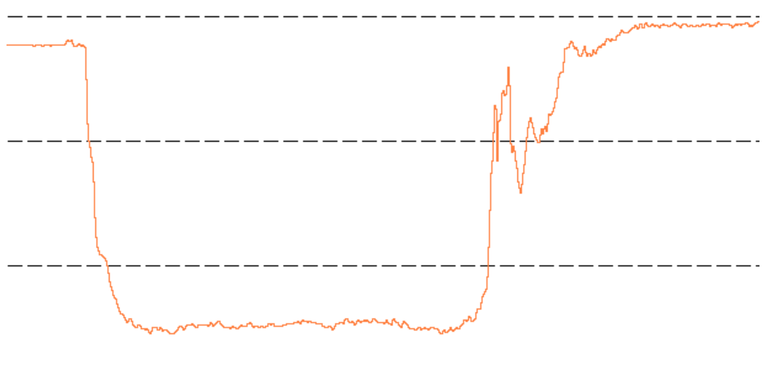

Figure 7 Tapping with slag transfer at the end

It can be noted that the signal noise varied during the trial due to differences in the tapping stream integrity. For the purpose of the study, all heats signal data were assessed manually with respect to the following factors:

- Normal tapping – the EMLI signal trend typical of a successful tapping with no slag transfer.
- Slag tapping – the EMLI signal trend is typical of a slag tapping at the end of the tap.
- Abnormal tapping – the EMLI signal trend shows an anomaly such as partially open tap-hole or slag tapping midway through the tapping process.

OBSERVATIONS

When studying the reversion rate for manganese and phosphorous oxides related to the selected heat groups "Normal tapping" and "Slag tapping", it is indicated that the reversion is larger in the group "Slag tapping", **Figure 8**. As mentioned above, it is reasonable to assume that this is due to that a phosphorous-rich slag from the electric arc furnace is transferred to the ladle furnace where, to some extent, it is reduced.

This indicates the importance of having good control of the EAF tapping process.

It was concluded that those heats where the EMLI-SIF system slag signal was used to stop tapping had a lower reversion of phosphorous in the ladle furnace compared to those that had been stopped purely based on visual slag indication.

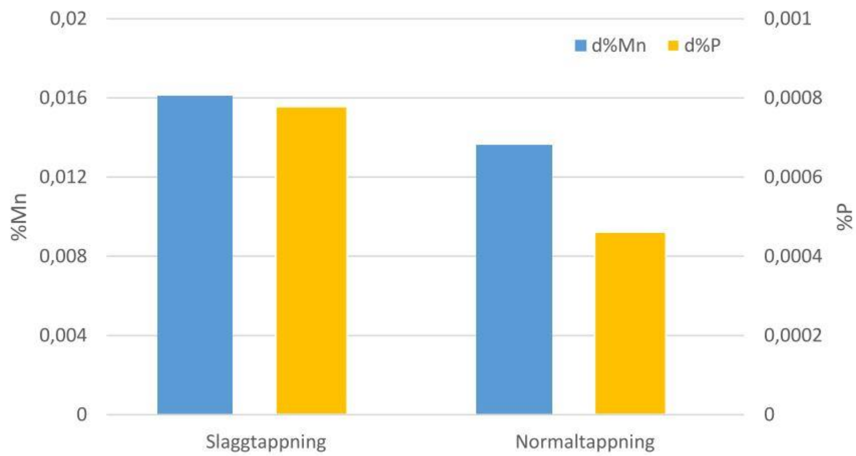

Figure 8

Tapping process rating
Manual observations on-site were compared with the signals from the EMLI-SIF system which showed that the principle employed also can be used to obtain a measure on how well each tap works in terms of degree of metal filling the tap hole.

Operator practices
Operator handling of the tapping procedure varies between individuals, perhaps mainly due to different experience and training. A general observation is that the more experienced operators are more likely to intervene by tilting the furnace manually as soon as the tapping stream lost force and/or slag was detected.

RESULTS AND DISCUSSION

The results and observations of the study confirmed that the EMLI-SIF system is an effective operator support to enable more reproducible furnace tapping where excessive slag tapping is avoided. The excessive slag carry over from the electric arc furnace will have a negative impact on the subsequent steel treatment.

With the use of the EMLI-SIF technology the potential benefits are promising: Tapping of the electric arc furnace will be less dependent on operator interpretation and skills, which is expected to minimize slag carryover and, thus, the slag carry-over negative effects on sub-sequent processing will be minimised.

Whatever the underlying factors, a slag-free tapping to stabilize the thermodynamic conditions in the ladle furnace is important. The value of this stabilization must be weighed against the cost of today's instability where margins have widened to avoid problems such as:

- Loading of purer raw materials than necessary to cover up for the variation.
- "Excessive treatment" to ensure that contaminant levels are below specifications.
- Lower guaranteed product quality to the customer in order to cover the most extreme cases.

Less furnace slag carryover increases process stability at the ladle furnace which results in improved process, production and product quality advantages. In the longer run increased process stability is of strategic value as it is in many cases a prerequisite for improved future productivity and quality.

The EMLI-SIF system was permanently installed and commissioned during 2015. The installation included a separate operator panel for direct operator feedback allowing for prompt corrective actions. The installation and commissioning was conducted within three days onsite, following the same proven installation concept as used for the trial.

CONCLUSIONS

When using the AGELLIS EMLI-SIF slag detection system at the Atomizing Plant in Halmstad electric arc furnace tapping a clear correlation was obtained between heats with detected slag tapping and undesired slag phosphorous and manganese reversion in the ladle furnace process.

The results confirmed that the EMLI-SIF system can be used as an effective and direct operator support to enable more reproducible taps where excessive slag tapping is avoided in order to obtain improved ladle furnace processing and greater production stability, as well as increased product quality.
Based on the tests results Höganäs Atomizing Plant in Halmstad decided to install the system on a permanent basis during autumn 2015.

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