THE HOLISTIC APPROACH FOR EFFICIENT SCRAP MELTING[1]

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Abstract

The efficient use of resources in form of raw materials and energies is leading more and more to developments around the electric arc furnace. One of these developments is the electric arc furnace HeatOpt system from Siemens VAI that is continuously monitoring the furnace off-gas, the off-gas flow and the slag level and controlling the input of natural gas, oxygen for refining and post-combustion and carbon for slag management. The HeatOpt (Holistic energy and transparency optimizing) system consists of four main parts: The holistic process model – a combination of algorithms and prediction strategies, the LOMAS off-gas analyzing system, the SAM off-gas flow analyzer and the FOX300 as slag foaming indicator. This arrangement was successful implemented and tested in cooperation with Steel Dynamics Inc., Roanoke (USA), Siemens Industry Inc, Canonsburg, PA (USA) and Siemens VAI Metals Technologies GmbH & Co in Germany and Austria in November 2011 and finalized in April 2012 with an economic benefit of more than 2US $/ton liquid steel.

Key words: Heatpt; Electric steelmaking; Off-gas measurement; Lomas gas analysis.

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1 THE CHALLENGE

Today the increasing demands to lower production costs and increase product quality, ever more stringent environmental requirements and highest availability with minimum operator personnel makes an improved operator support system to an essential element in electric arc steelmaking. Nevertheless most existing solutions only deal with specific sub-systems of electric arc furnaces.

Figure 1. Electric arc furnace – the initial part for efficient and sustainable steel making.

Controls are separately performed for burners, electric arc power, post-combustion and carbon management. These controls are time or energy related; an integrated, closed-loop solution for all material flows has been implemented only in parts.
This low level of automation and the restriction on specific elements lead to a suboptimal use of resources like electric power and chemical additives. The furnace is mainly managed by the experience of the operating staff. Therefore it is difficult to comply with a constant efficiency. For a continuous and cost-efficient operation of an electric arc furnace the following requirements for a new closed-loop control can be defined:

- holistic approach for all furnace sub-systems and components;
- modular composition of the system allowing for specific furnace configurations;
- application of modern sensors and measurement technology to get a high level of transparency, especially using off-gas composition, flow analysis and slag level measurement;
- Immediate feedback by closed-loop control of all material flows.

2 OUR SOLUTION

Our solution is the use of information from the Lomas - Low maintenance gas analyzing system - that gives the composition of the furnace off-gas - oxygen, hydrogen, carbon monoxide and carbon dioxide and natural gas. Further, the output of the SAM (Single Air Measurement of Velocity and Flow) off-gas flow measurement

and the FOX300 slag level indication are used for an advanced holistic process model. This includes algorithms and prediction strategies for closed loop control of injection of natural gas, oxygen, carbon and the power input.
Main difference of the holistic control to most existing systems is reaction corresponding to the actual process conditions respectively the actual furnace behaviour. This represents a significant progress compared to the usual, rigid time and energy related control diagrams.
Main features of HeatOpt are a minimized and efficient process-related use of natural gas, oxygen and carbon, based on proper adjustments of main operating parameters. Further, the saving of energy - either electric and / or fossil energy - based on process conditions and the reducing of tap-to-tap time as well as a higher level of transparency of the process.

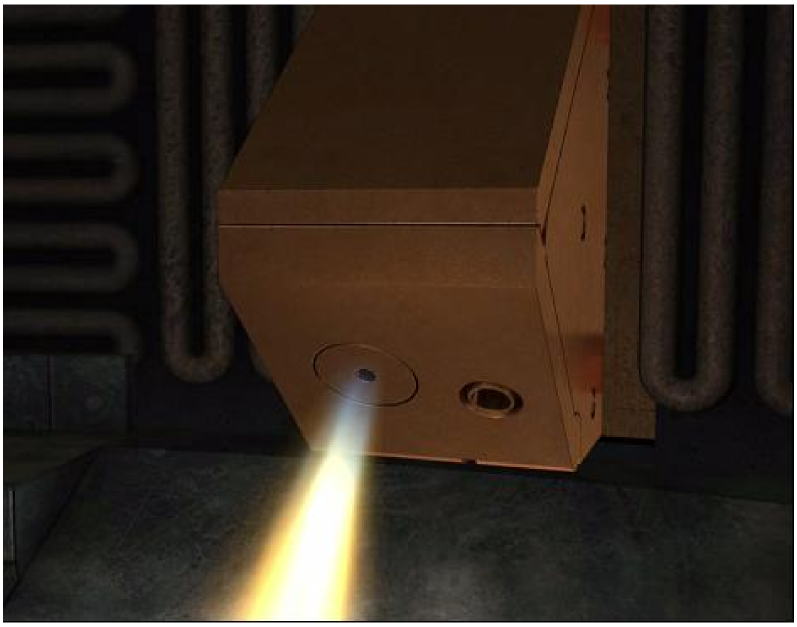

Figure 2. RCB technology for optimized use of natural gas, oxygen and carbon.

3 GENERAL SYSTEM ARRANGEMENT

The general system arrangement and function is visible in the electrics & automation hardware layout (Figure 3). A communication network between measurement systems (Lomas, SAM, FOX300), the HeatOpt control unit and the customer PLC is realized via Profibus and Ethernet. Based on measurement systems integrated in Siemens PLC, an easy adaptation in existing furnace periphery could be realized. Combined with the furnace conditions and status information of the customer's PLC, all detailed process information for the holistic process model with the included algorithms - for modification of set values for oxygen, carbon and natural gas - are available.

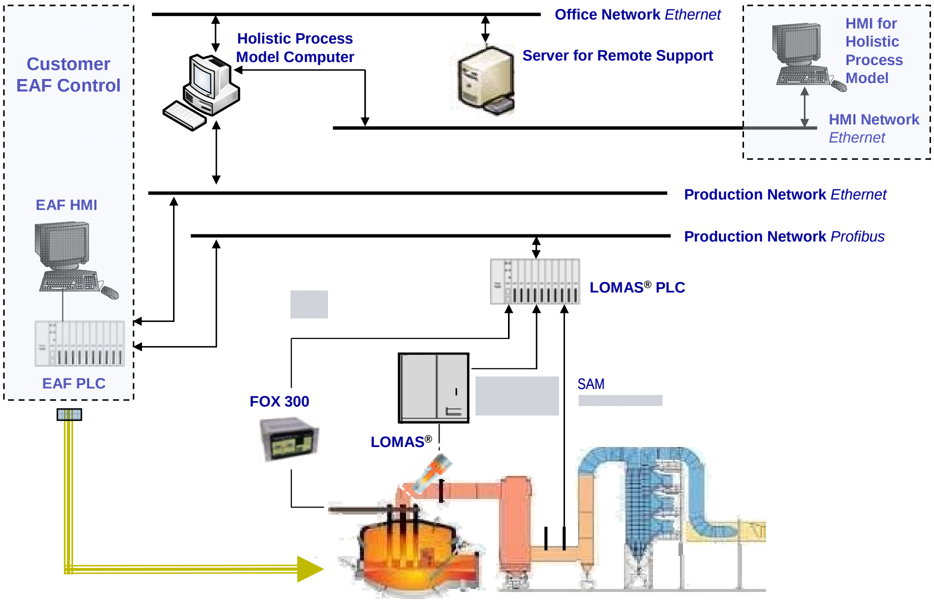

Figure 3. General system arrangement for flexible and fast installation in existing furnace area.

4 MEASUREMENT TECHNOLOGIES

The Lomas system with its patented gas sampling probe represents a sophisticated low maintenance gas analyzing system, performing with highest availability and providing safety and explosion protection. The probe has proven its reliability and sustainability in numerous installations of more then 140 in BOF primary off-gas ducts worldwide. For the EAF application the probe was further improved and adapted, especially with focus on abrasion protection, cooling and thermo-mechanical stress like thermal expansion.

Figure 4. Lomas probe retrofit in the off-gas duct.

The probe is located in the off-gas duct (Figure 4) and is cleaned automatically. The Lomas system offers high accuracy in measurement and data evaluation and could demonstrate an availability of more than 99%, even under extremely hot (up to 1.800°C) and dust-laden (up to 2.000 g/Nm^3) gas conditions. The system further contains a self-checking logic which automatically induces different switching/cleaning steps if different gas analysis and gas treatment parameters (e.g. gas flow, temperature etc.) reaches critical values.

Figure 5. Lomas container including off-gas cleaning, preparation and analyzing technology.

Extremely short response time (t_{90}) of far less than 15 sec. (depending on site conditions) and continuous, high-available and accurate measurement of CO, CO_2, H_2, O_2 and CH_4 make this probe leading in EAF operation.

Routine checks are required only twice a month and maintenance work will not exceed eight hours two times a year. A further benefit of this system is its fast warning procedure for dangerous situations i.e. high contents of O_2 and H_2 during melting and refining process as well as CO/ H_2 detection for protection of the plant's dedusting system.

For mass and volume calculations, the off-gas flow is analyzed with the SAM system. This system – one pair of sensors per duct - uses the tribo-electric cross correlation technology to realize extremely short response time. The gas velocity is determined via the transport velocity of the particles in the off-gas stream. Combined with the duct dimension and a temperature reading, the volumetric flow will be determined directly. For the HeatOpt system, a repeatable online gas flow measurement with highest accuracy, linear measurement characteristics and not affected by particles has been realized. It operates with dust concentrations from 1 mg/m³ to 2,000 g/m³ and temperatures up to 1,100°C. The system is easy to retrofit into existing ducts (Figure 6).

Figure 6. Outside view of the SAM sensor in the off-gas duct - simple modification and application.

For an accurate and easy to implement slag foaming monitoring system, the FOX300 solution made by Siemens VAI is included. The system uses Rogowski coils to analyze the high current harmonics to measure and calculate a slag foaming index.
The HeatOpt-system was successfully implemented and tested in cooperation with Steel Dynamics Inc., Roanoke (USA) for an 100t electric arc furnace with 65 minutes tap-to tap time and 3 injector units each for carbon, oxygen and fine coal.

5 CONTROL STRATEGY

The main difference of the holistic control of the HeatOpt to most existing systems is the ability to react to current process conditions in the EAF. This represents a significant progress compared to the usual, rigid time and energy related control diagrams. In this first installation at SDI the natural gas injectors were optimized, the oxygen lances and the carbon injectors were controlled.

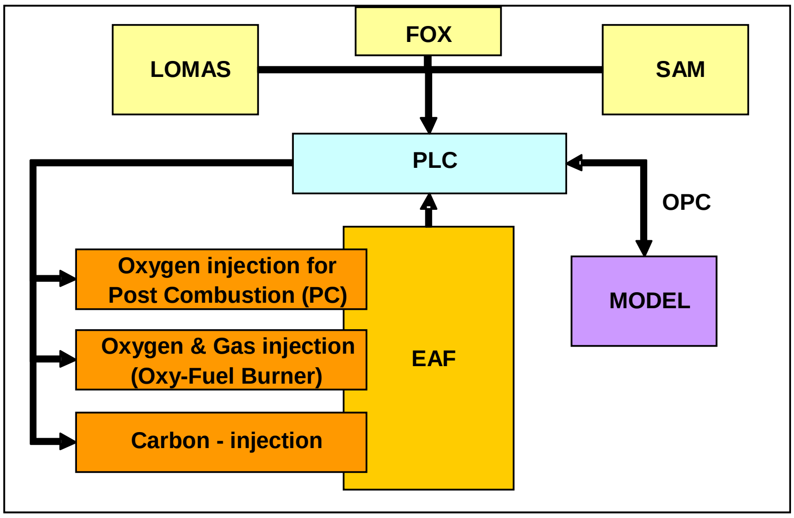

Figure 7. Main components of the system architecture.

The burner-control is divided into two main parts. The first part deals with the flame-backstroke, the second part considers to use the burners just as long as they are efficient. For each part representative cooling panels are selected. Aim of the burner control is an energy efficient usage of the natural gas injectors. For this purpose, an efficiency limit for using each burner is derived from the mean temperature of the cooling system. At the beginning of the melting process for each basket the prevention of flame-backstroke as well as a defined reaction in case of a flame-backstroke is essential for avoiding damage of the panels. Prevention and detection of flame-backstroke are based on the temperature of the cooling water from selected panels. The ratio of burner oxygen to natural gas is dynamically adjusted using the measured off-gas CH_4 content together with an integrated solution for post-combustion-oxygen-control, which is described below.
The start of the oxygen-injection is linked to reaching the efficiency limit for associated burners. A key factor for the control of the oxygen-injection flow rate is the balance between the oxygen and the carbon in the steel and slag. In this context the measured off-gas composition and flow rate allow to retrieve valuable information about the oxidation state. For adjusting the carbon and oxygen-injection flow rates information from the Celox measurement is additionally taken into account.

Aim of the carbon-injection control is to generate and preserve foaming slag conditions by injecting a sufficient amount of carbon, but on the other hand, avoid the depletion of FeO from the slag and wasting carbon. For the assessment of foaming slag conditions the signal of the Fox300 is used. Additionally the measured off-gas composition and flow rate are used to dynamically react based on the oxidation state. The required carbon-injection rate can be realized via pulsing and modulating the length of the switch-on and switch-off intervals.

Figure 8. Inside view of the Lomas probe.

The closed loop control of the post-combustion-oxygen flow rate aims at keeping the post-combustion ratio defined as the ratio of CO_2 / (CO + CO_2) content in the off-gas at an acceptable level. On the other hand the post-combustion-oxygen flow rate is reduced automatically when the content of free oxygen in the off-gas exceeds a certain limit in order to avoid negative impacts especially on the electrode consumption. Basis for the control is the calculation and online adaptation of the yield factor of the post-combustion oxygen and the amounts of C and O_2 in the off-gas during production of a heat using measured off-gas composition and flow rate. Within the implemented solution special provisions have been made to comply with the response time of the extractive off-gas measurement method. Additionally the temperature of the cooling water from selected panels is taken into account. In case of high temperature of the cooling water the oxygen flow rate for the post-combustion oxygen injectors is reduced, in order to avoid too much strain of the panels.

6 OPERATIONAL RESULTS

Based on this control algorithms and the overall process strategy the details were discussed with the customer (SDI) to fulfill his needs. Final target was to reduce the conversion costs of the EAF. A first effect was that the electrode consumption has been reduced by lowering the oxidation state of the EAF. Detected by the Lomas analyzing system in the first place SDI reduced the power of the fans respectively the fan speed in the bag house.

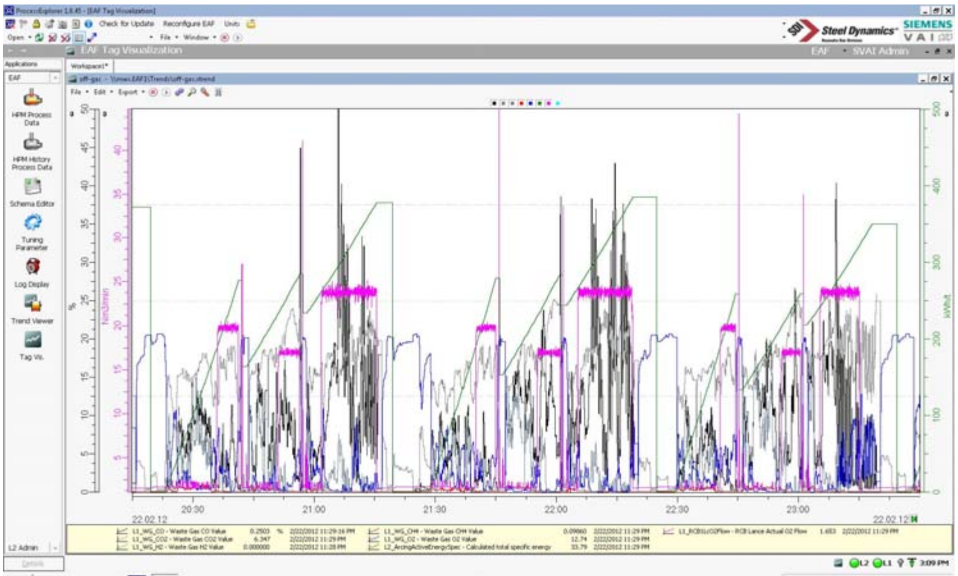

Figure 9. Example of 3 hours off-gas chemistry - visualized for operator and controlled by holistic process model.

With the output of the Lomas gas analysing system and SAM (Figures 9 and 10), the set points of oxygen and carbon injectors were modified and the Level1 parameters adapted.

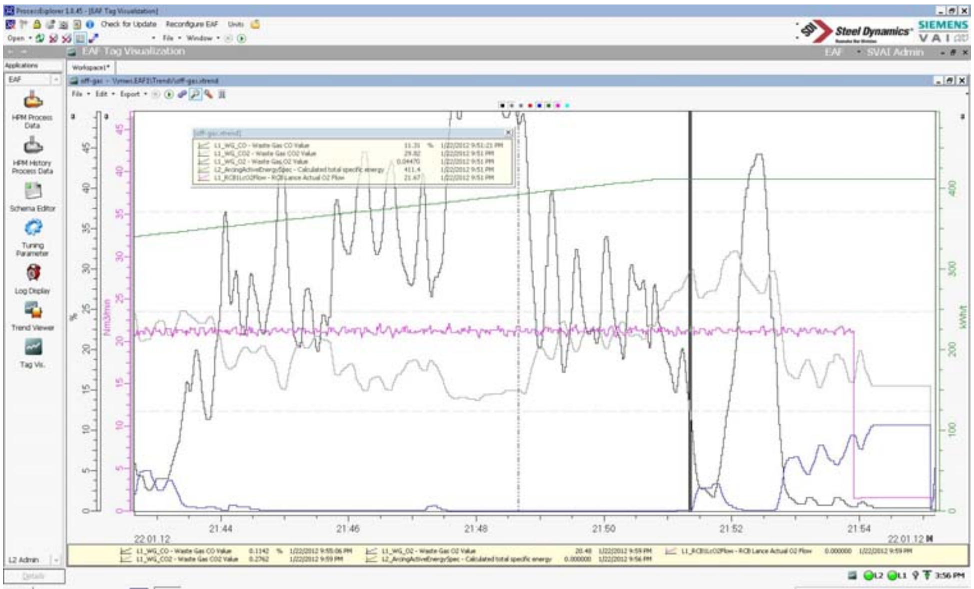

Figure 10. Last 20 minutes of a heat - visualized for operator and controlled by holistic process model.

So the power-on time was reduced by 2.6%, the productivity increased by around 3.6%. The oxygen consumption was reduced by around 14%, the natural gas consumption by around 18%. In combination with an optimized carbon management the injected carbon was reduced by 5.78% on average. This leads also to a reduced electrode consumption of 1.3%. Based on the aggregated savings of above mentioned operational benefits Siemens expects and is ready to guarantee an economic benefit of 1.5 US$/t of liquid steel produced. Depending on the current production volume at SDI Roanoke, the pay back period shall be within a year or less. These guarantee figures could have been verified by saving more than 2 US$/ton liquid steel.

7 CUSTOMER BENEFIT

By continuously monitoring the EAF off-gas and off gas flow rate and by processing the measured values with the holistic process model the operational benefits could have been improved by the tests in SDI.
The instant feedback from the process like charge material condition changes, for example deviations in charge carbon amounts, burner/jet operation in terms of proper gas/O_2 ratio adjustments, carbon injection amounts and post combustion control lead to a proper adjustment of main operating parameters for the Burner/O2 Injector units and avoids instances of excessive or non sufficient oxidation processes.
The main benefit of the holistic control to most existing systems is reaction corresponding to the actual process conditions respectively the actual furnace behaviour. So the process is individually managed and optimized.
A further benefit of the system is increased safety by detecting potential hazardous conditions such as water leaks in the furnace.

8 CONCLUSION

The system was designed to fulfil the overall target - to reduce the overall energy, the electrode consumption, the jet-oxygen and burner-gas consumption as well as increased augmented metallic yield and productivity. This system was successfully implemented and tested in cooperation with Steel Dynamics Inc., Roanoke (USA) and the overall targets were achieved and exceeded. Special thanks to SDI for their support and the strong partnership.