Optimizing arc furnace foaming slag process

How vibration sensors offer an effective tool for controlling the process, minimizing resource utilization, and reducing CO_2 emissions

A White Paper from Siemens Metals Technologies

Abstract

Controlling the height and distribution of foaming slag is one of the most challenging aspects of steelmaking in an electric arc furnace (EAF) process. Many plants use automation technology to provide technicians with clear and easy-to-understand information and facilitate the steelmaking process. But implementing a system to visualize and optimize the conditions within an almost sealed furnace vessel has remained an elusive achievement – until now.

This paper explains how operators can use proven vibration-detection technology to precisely manage foaming slag operation. With this type of control system, operators can now ensure complete and stable slag coverage of the steel bath and arc throughout the EAF flat-bath period. Achieving a uniform and reproducible slag distribution conveys many operational benefits, including increasing furnace productivity, reducing carbon consumption, and lowering energy usage and carbon dioxide (CO_2) emissions.

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The EAF Industry has a great track record of innovation

Electric arc furnace (EAF) operators are not afraid of change. In fact, they have met many challenges over the last 40 years by embracing new production strategies and technologies. By capitalizing on improvements in automation technology, they have been able to optimize many aspects of production, including oxygen blowing, oxy-fuel, water-cooled walls and roofs, bottom tapping, hot-heel charging, computerized monitoring, scrap preheating, and high secondary voltages.

In combination, these process changes have enabled EAF operators to dramatically improve operational efficiency – while at the same time lowering labor and material costs. As a result, the industry has been able to reduce electrical energy consumption from 630 kWh to 350 kWh, tap-to-tap times from 180 minutes to 45 minutes, and electrode consumption from 6.5 kg to 1.5 kg[1].

Equally important for EAF operators, they have realized these improvements while increasing their overall market share to more than one-third of worldwide steel production.

Now, EAF operators are weighing a new opportunity for further process improvement, one that promises to make metal production even more efficient and affordable by better controlling one of the most complex steps in the steelmaking process.

Improving Slag Foaming

First, let's review a little background.

Foamy slag formation remains one of the trickier aspects of steelmaking in an EAF environment. In a typical plant, automation technology provides technicians with clear and easy-to-understand information about the steelmaking process. But visualizing the conditions within a furnace vessel remains challenging, and manual control to optimize the process is still a common practice.

Achieving an optimal slag layer is critical to promoting low thermal conductivity, removing undesirable elements from the molten steel, shielding the electric arcs, and protecting the furnace's fireproof lining. Technicians typically use predefined operating diagrams or manually inject carbon fines and oxygen while not being able to directly observe how these manual injections are influencing the height and distribution of the foaming slag.

Too often, technicians must infer the height of the foaming slag by measuring furnace state variables and interpreting external cues. Unfortunately, this approach is not precise enough to optimize the automatic foaming-slag method or reliably control the dynamic, dangerous, and noisy conditions that occur inside a furnace.[2]

Traditional methods of controlling foaming slag rely on a combination of static programs and operator intuition to guide critical judgments that ultimately can affect steelmaking costs and product quality. Technicians, although skilled, are forced to control the foaming slag process using imprecise modeling that represents the conditions within the furnace.

While workers undoubtedly strive to do their best, inaccuracies in the automated process along with misjudgments contribute to higher energy costs, higher injection carbon usage, accelerated electrode wear, and, potentially, premature wear to the refractory walls. The question that has long dogged EAF operators is, can we do better? Can we ensure consistent results from a process that is inherently difficult to visualize?

The answer, based on recent innovations explained below, is an emphatic yes!

Using sensors to better manage industrial processes

In the late 1990s, researchers in Europe experimented with using online control to improve slag foaming in a DC-based EAF.[3] For their experiment, they mounted a sonic meter near a control room and used it to record sound waves emitted by a nearby furnace.

[1] Steel university data for 1965 to 2005, www.steeluniversity.org/content/html/eng/default.asp?catid=25&pageid=2081272028
[2] "Development of an Acoustic Sensor for Electric Arc Furnaces," Chemical Technology, December 2006.
[3] "On-line Control of the Foamy Slag in EAF;" Christian Marique. Pierre Nyssen, and Philippe Salmone; 1999; Center for Research in Metallurgy.

By monitoring volume-level changes, the researchers were able to determine some conditions within the furnace vessel and use outputs from an inline control system to inject carbon and oxygen into the foaming slag layer. While this control method was not commercialized, it did suggest that sensors and automation could be used to provide more precise and consistent control of the foamy-slag height and distribution.

Interestingly, there is strong precedent from other industries for using vibration sensors, another type of accelerometer, to capture reliable, accurate, and cost-effective data for advanced control systems. Industries such as wind power, transportation, pharmaceuticals, marine shipping, paper manufacturing, and coal mining have all made extensive use of vibration sensors to promote safety, reduce maintenance costs, and optimize critical processes.

Industrial operations are frequently loud, dangerous environments, where complicated and expensive equipment must operate with minimal downtime. One of the notable characteristics of vibration monitoring systems is that they are quite effective in these harsh conditions. Vibration sensors typically do not have moving parts and are easily ruggedized to withstand extreme temperatures or other challenging environmental conditions.

Utility-scale wind farms, for example, which have become quite numerous in the 21st century, often consist of hundreds of massive turbines spread across thousands or hundreds of thousands of acres.[4] Ensuring turbine uptime is essential, but sending skilled crews for routine maintenance checks on rotor hubs perched 300 feet above the ground (or over the waves) is inefficient.

With vibration monitoring systems, wind farmers are able to keep an eye on critical components remotely and proactively. If telltale high- or low-frequency vibrations suggest a bearing or gearbox component is failing, they can acquire a component and undertake a repair before the issue causes damage or diminishes electricity production.

Industry data suggests monitoring in this way makes a huge difference on maintenance costs. Replacing a worn bearing is a relatively simple $5,000 procedure. But allowing that bearing to fail might result in a catastrophic gearbox or generator malfunction that would cost $245,000 to repair.[5]

Railroad companies are likewise interested in preventing small problems from turning into major incidents. That's why they began using data from vibration sensors in the early 1980s to detect thermal cracks in wheel rims during offline inspections. Higher-quality wheels on cars promote transport reliability and lessen the chance of an accident or derailment that could cost millions of dollars to remediate.

Within the last few years, the Union Pacific Railroad has supported a development effort to create a new technology for monitoring wheels after they go into service on rail cars. In this case, vibration sensors monitor the wheels on passing trains for conditions that suggest fatigue or abnormal performance. The sensors are tied to wireless devices and fiber-optic networks that relay data to analytical software with functions for alerting personnel, scheduling maintenance, slowing train speed to reduce risk, or even removing trains from service.[6]

Similar technologies are used to test many types of complex machines. In fact, nearly any device with rotating or reciprocating parts can be monitored and diagnosed in real time along with data tags indicating temperature, pressure, position, and speed at specific points in time. New generations of piezoelectric vibration sensors and control hardware are being used to monitor conditions in trackless mining operations, refrigeration warehouses, and process and beneficiation plants.

Now, EAF operators have the opportunity to capitalize on the lessons learned in these industries.

[4] "Wind Farm," Wikipedia, http://en.wikipedia.org/wiki/Wind_farm
[5] "Wind Energy," Window on State Government, www.window.state.tx.us/specialrpt/energy/renewable/wind.php
[6] "Rail technology development at Union Pacific," Rail Magazine, www.progressiverailroading.com/union_pacific/article/Rail-technology-development-at-Union-Pacific--31254

Using vibration sensors to better manage foaming slag behavior

By leveraging proven vibration-detection technology, operators can now use a well engineered control system to ensure a complete and stable covering of the steel bath and arc throughout the flat bath period. Achieving a uniform and reproducible slag distribution conveys many operational benefits, including increased furnace productivity, reduced carbon consumption, and lowered energy usage and carbon dioxide (CO_2) emissions.

Pilot projects dating from 2008 validate that installing such a system is a manageable and affordable process. As indicated in the diagram of a three-phase EAF depicted in Figure 1, each ruggedized vibration sensor is mounted on an adapter plate opposite the electrode it monitors. High-temperature shielded signal cables, which are easily removed if the operator needs to change the vessel, network the sensors to a central controller.[7]

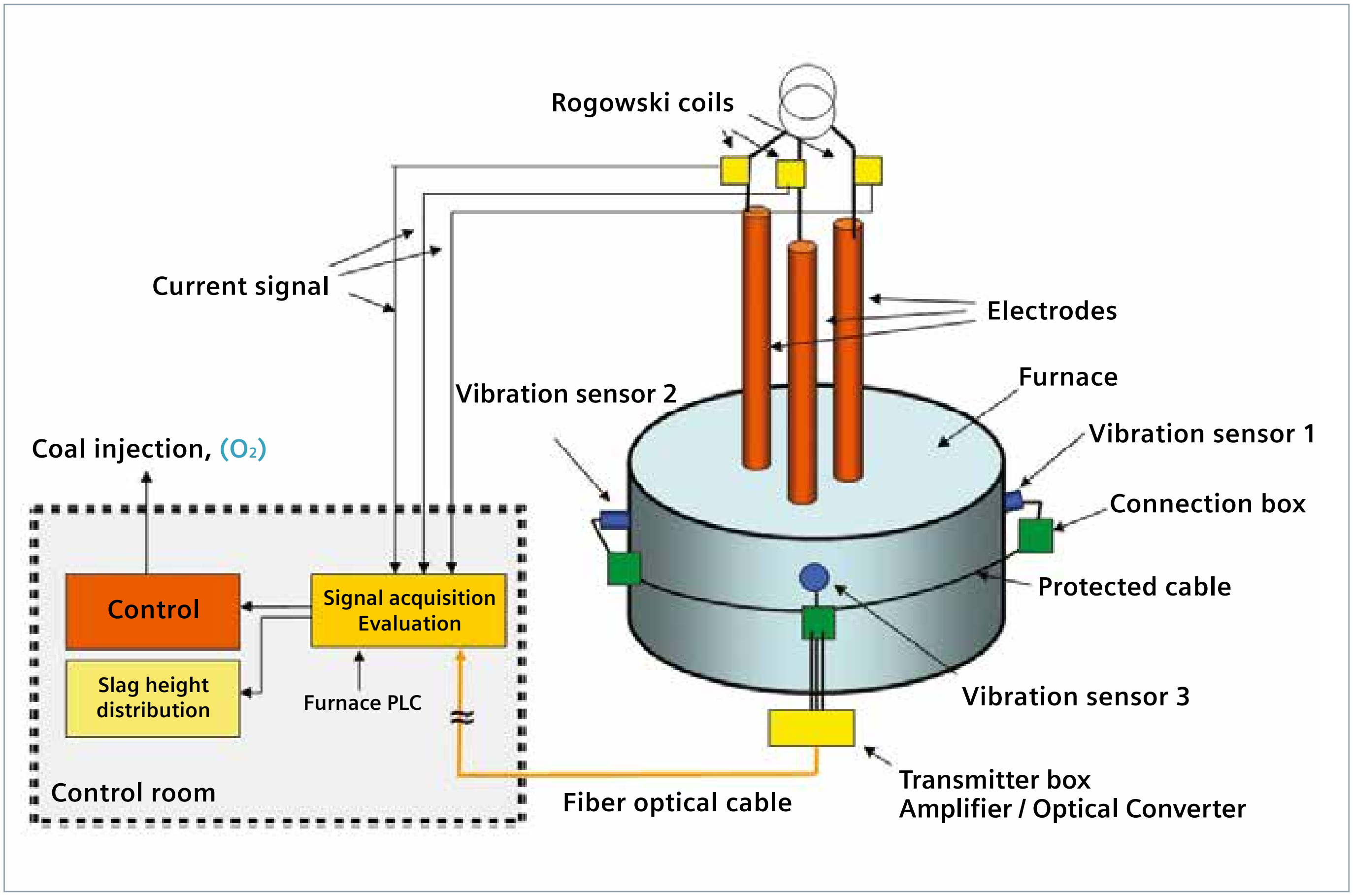

Figure 1. Typical configuration of a vibration sensor system

[7] "Results of Foaming Slag and Scrap Meltdown Control SIMELT CSM/FSM Based on Structure-Borne Sound in Electric Arc Furnace Operation;" Thomas Matschullat, Detlef Rieger, Bjorn Dittmer, Klaus Kruger, Arno Dobbeler, and Helge Mees; AISTech 2012 Proceedings.

The structure-borne sensors detect vibrations generated by the electric arcs which are transmitting the vibration through the steel, slag and gas phase. The control module evaluates structure-borne sound data and current signals using algorithms, which in turn regulate the injection of carbon (and oxygen) into different areas of the furnace.

The control module detects the conditions inside the furnace and uses the information immediately to optimize slag conditions. For example, the control module can determine if the slag level is low in a particular area and apply injection carbon as needed.

By measuring three current and vibration signals and evaluating the weight of the charged scrap along with the furnace's tilting angle and transformer taps, the module is able to automatically regulate the injection of carbon and oxygen so as to precisely regulate the foaming slag's height and distribution.

Visual displays (Figure 2) provide two- and three-dimensional representations of what is occurring inside the sealed furnace wall in near real time. By calculating the damping of the sound propagation, the controller determines the height of the foaming slag not just close to the electrodes but also in the complete area between the electrodes and the furnace shell.

As indicated in Figure 2, the height of the slag determines how much of the electrode arc sound and vibration is propagated to the furnace shell. The controller registers the damping effect of the vibration and uses a transfer function to compute the height of the foaming slag.

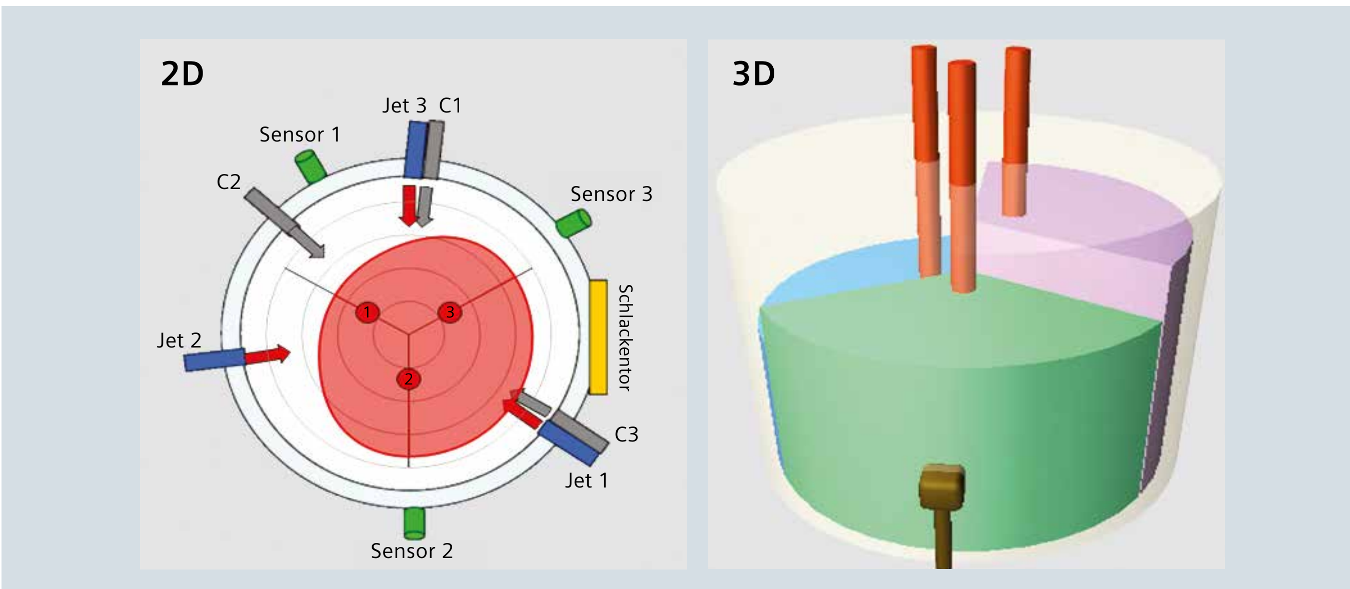

Figure 2. Representations of the 2D and 3D information the sensors are collecting

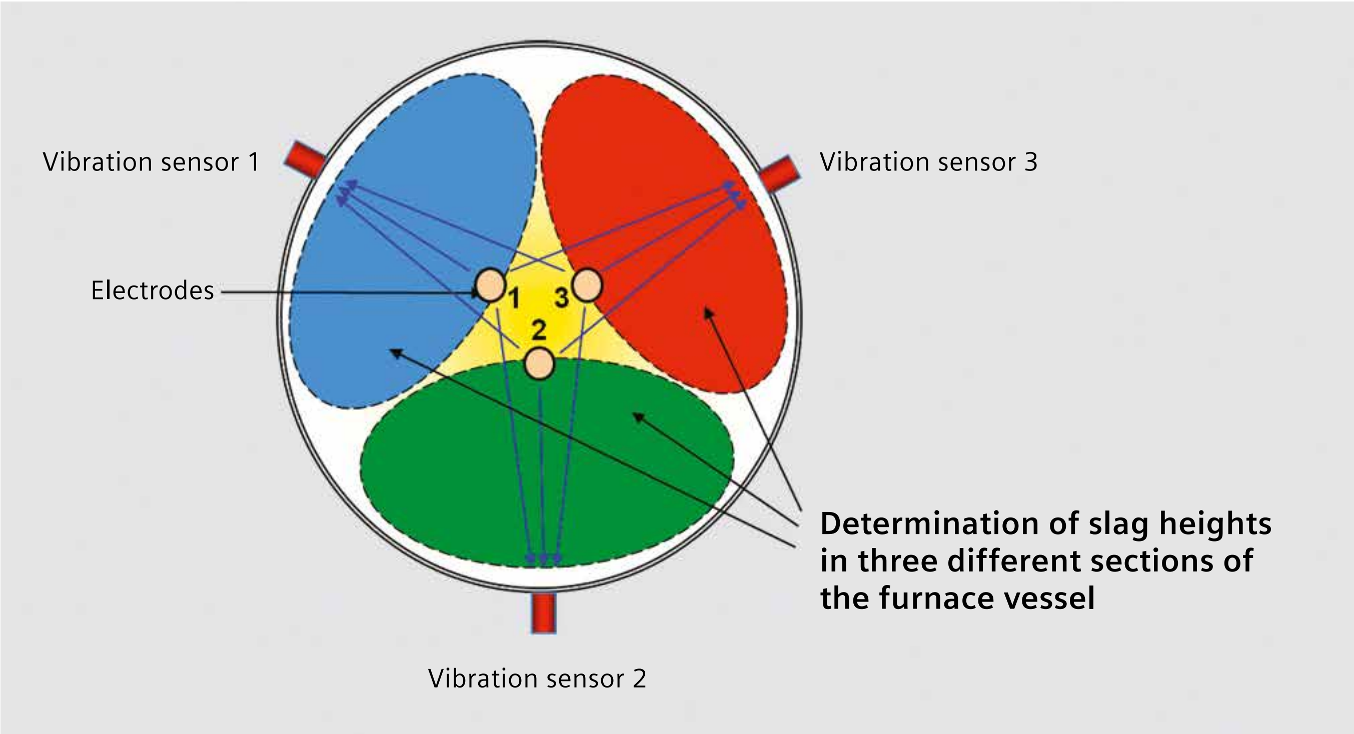

Figure 3. Complete coverage of the slag layer is possible using a vibration-system array

A fuzzy algorithm calculates the slag height for each zone in almost real time and then automatically adjusts the steelmaking process to ensure a uniform slag distribution. Accurate data for each zone (Figure 3) means it is possible to inject precise pulses of carbon into the foaming slag and maintain optimal conditions until the end of the melt, at which point part of the foamy slag is poured out. Because the system is fully automated, control of the foamed slag process is precise and reproducible from start to finish.

Results for Several Operational EAFs with Vibration Sensors

Data from four EAF furnaces with tapping weights of 80 to 150 tons indicates that using a vibration-sensor based control system can greatly improve production outcomes. These installations, which produce rebar and special bar quality steel, on average saved close to 30 percent on injected carbon while reducing power-on time by 14 percent. The researchers also reported improved tap-to-tap times between 9 percent and 13 percent along with a two to three percent reduction in electricity consumption.[8]

Lowering carbon and energy consumption provides an added environmental benefit. In these installations, the operators calculated estimated CO_2 reductions of up to 14,600 tons per year for two furnaces running 24 heats per day over 300 days.[9] Equally important, they projected cost savings for energy, carbon, and production at approximately $1.50 U.S. per short ton of steel.

Better control means these furnaces were able to more quickly reach target values for oxygen content in the heat. That contributed to more consistent conditions during production with less use of resources.

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[8] "Results of Foaming Slag and Scrap Meltdown Control SIMELT CSM/FSM Based on Structure-Borne Sound in Electric Arc Furnace Operation;" Thomas Matschullat, Detlef Rieger, Bjorn Dittmer, Klaus Kruger, Arno Dobbeler, and Helge Mees; AISTech 2012 Proceedings.
[9] "SIMETAL SonArc FSM and CSM" Arno Dobbeler and Bjorn Dittmer, Siemens VAI, 2012.

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