Workshop R&D on Electrical Arc Furnace: state-of-the-art of RFCS-supported projects

Sensors and Measurement Techniques for Process Control

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“Necessity is the mother of invention” (Platon)

Major drivers for innovation related with the electric arc furnace are:
- Improvement of energy efficiency
- Improvement of resource efficiency
- Improvement of steel quality
- Improvement of safety

Source: Tenova State of the art in EAF technologies, 2nd VDEh-AIM Joint Meeting on Metallurgical Fundamentals
## Evaluated RFCS research projects directly dealing with EAF sensor based process control

<table>
<thead>
<tr>
<th>Contract Report</th>
<th>Title</th>
<th>Participants</th>
<th>Date Start / End</th>
<th>Topic regarding sensors</th>
</tr>
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<tr>
<td>RFSR-CT-2004-00008</td>
<td>Control by camera of the EAF operations in airtight conditions</td>
<td>CSM, BFI, AM R&amp;D, CORUS UK, MORE SRL</td>
<td>2004-07-01 to 2007-12-31</td>
<td>To observe the scrap-melting process under slag-door closed conditions, a camera-based technology to observe furnace events during meltdown has been developed. The camera system is able to see through combustion gases by selecting its wavelength to be in the mid-infrared spectral band.</td>
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<tr>
<td>No 7210-PR/204</td>
<td>Innovative continuous online determination of steel melt temperature by direct optical measurement in the melt</td>
<td>BFI, AG Dillinger Hütte, CRM, Aceralia</td>
<td>2000-07-01 to 2003-12-31</td>
<td>Based on a detailed analysis of the state of the art a fibre optical measurement technique was promising to meet the demands of the requested applications. The measurement principle is to feed a standard low cost optical fibre continuously into the steel bath and to analyse the radiation transmitted through the fibre for information on bath temperature.</td>
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<tr>
<td>RFSR-CT-2013-00002</td>
<td>Determining process conditions for online monitoring of temperature and carbon content in the electric arc furnace to optimise end point control</td>
<td>BFI, FERRIERE NORD S.P.A., POLITECNICO DI MILANO, SAARSCHMIEDE</td>
<td>2013-07-01 to 2016-06-30</td>
<td>Online measurement systems for continuous monitoring of the process status during EAF treatment and end point control will be developed and applied. At one furnace an accretion free melt access will be created for fibre-optical temperature measurement. At another furnace a measurement system for combined optical determination of carbon content and temperature will be developed using a lance access.</td>
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Steel bath temperature sensor technologies

Thermocouple Type MMT10-1200-Fe

1. Paper tube
2. Thermocouple type S
3. Ceramic housing
4. Protection cap steel
5. Paper cap

Thermocouple Type MLTS-1200-Fe-P

1. Paper tube
2. Thermocouple type S
3. Ceramic housing
4. Protection cap steel
5. Paper cap
Optical steel bath temperature sensors

- Immersed fibre-optical steel bath temperature measurement is:
  - Independent of emissivity
  - Continuous measurement of melt temperature during fibre feeding
  - Fast response time by optical measurement
  - No influence by melt bath surface or slag cover
  - Available also during heating operation, because insensitive against electromagnetic fields
  - Precise temperature control to reach the desired target temperature
Optical temperature measurement sensors (EAF)
RFCS-No 7210-PR/204

- Optical fibre temperature measurement based on lance/manipulator technique
- Two flexible hoses connected to the probe (one for the fibre and shield gas, and one for cooling gas) and the lance / manipulator

Results:
- The probe withstood the harsh conditions inside the furnace during 11.5 minutes, i.e. much longer than the application period for liquid steel temperature measurement in the EAF (last 5 - 6 minutes of each heat);
- That the probe could have been used for an additional measurement;
- The measured temperature signal shows a clear trend up, as expected
BFI developed an optical temperature measuring system based on manual lances, especially in small-to-medium sized foundries.

Technical data of mobile, lance based optical temperature measurement system DynTemp® H:

- Temperature measurement range: 1250°C to 1800°C
- Reproducibility of detector: ± 0,1% + 1 K
- Response time: 0,5 s
- Device dimensions: 0,8 m x 0,8 m x 0,35 m
Optical temperature measurement sensors (EAF/LF)

- Optical fibre temperature measurement based on lance/manipulator technique
- No influence of slag and oxides
- No electromagnetic influence on measurement
- Flexible measurement duration up to several minutes
- Tailored measurement probes
- Temperature measurement without interrupting the heating process
- Temperature measurement range: 1500°C to 1700°C
Optical temperature measurement sensors (EAF/LF)

- Measurement accuracy of the new process control DynTemp® is better than 2 K compared to thermocouple measurements.

- Shorter heating times can be detected, using the continuous temperature measurement (new process control), compared to thermocouple spot measurements (conventional process control).

- For a typical heat of 100 t more than 300 kWh\textsubscript{el} can be saved.
Optical temperature measurement sensors (EAF/LF)

- With efficient bottom stirring, homogeneous temperature of liquid steel in ladles
- Local DynTemp® measurement, reproducibility better than 2 K
- Continuous temperature measurement up to 90 s
Optical temperature measurement sensors (EAF/LF)

- Improved process stability with continuous temperature measurement by DynTemp® compared to short term measurement with thermocouple measurement and/or model.

- Without proper stirring for homogenization of liquid steel bath: temperature fluctuations up to +/- 30 K observed.
BFI has developed a robust continuous optical measurement system based on a consumable optical fibre fed through the bottom gas system into the liquid steel bath.

The system measures the actual steel bath temperature during the blowing process to determine accurately the required end of blowing.
Main benefits are:

- Short response time (< 0.1 s)
- Continuous online monitoring
- Easy application
- Improved process control
- Raising output
- Savings in oxygen consumption and time
Fibre-optical continuous temperature measurement (BFI DynTemp®) using

- Lance
- Bottom nozzle

- Monitor continuously the liquid steel temperature during the refining phase
- Determine process conditions to perform representative measurements in dynamic inhomogeneous melts
- Develop enhanced dynamic process control based on novel measurements
- Develop strategies and model-based set point calculations for exact determination of control parameters for accurate EAF end point control
- Evaluate availability, performance and limitations of continuous measurement
EAF bottom gas purging systems

- In EAF steelmaking where metallurgical constraints exist, bottom gas purging provides cost benefits by:
  - Increased thermal and temperature homogeneity in the steel melt
  - Decreased melting time of scrap and DRI.
  - Increased heat transfer during the superheating period.
  - Decreased specific electrical energy demand.
  - Increased chemical homogeneity in the steel melt
  - Decreased oxygen consumption.

Oxygen sensor technologies

**Oxygen Probe Type MIN-OXL-S-170**
- Low Level

1. Paper tube
2. EMK-Unit type S
3. Steel protection cap
4. Paper protection cap

**Oxygen Probe Type MIN-OX-28B-120**
- High level

1. Paper tube
2. EMK-Unit type B
3. Steel protection cap
4. Paper protection cap
Vibration and sound sensors

- The evaluation of structure-borne sound emissions in EAFs yields essential information about:
  - foaming slag behavior,
  - scrap shielding of the arcs
  - condition of scrap bulk

- Condition-based Scrap Melt-down control module (CSM)
- Foaming slag control module, also called SIMELT Foaming Slag Manager (FSM)
- help to improve energy efficient operations

Source: Results of foaming slag and scrap meltdown control SIMELT CSM/FSM based on structure-borne sound in Electric Arc Furnace operation, AISTech 2012
Vibration and sound sensors

- Use of the sensors leads to a smoother and forward-looking operation yielding in reduced heat load and a large reduction of transformer tap changes.
- Further on, a slight decrease in power-on time can be realized.

Number of total transformer tap changes before and after the SIMELT CSM installation, showing a pronounced decrease.

Specific power-on time in minutes per mt before and after the SIMELT CSM installation.

Source: Results of foaming slag and scrap meltdown control SIMELT CSM/FSM based on structure-borne sound in Electric Arc Furnace operation, AISTech 2012
The developed camera-based technology is an infrared camera for observing the process inside an EAF operating with closed slag door.

Recordings have provided new and interesting insights into the EAF melting process. Images showing:

- the melting characteristics of different size scrap pieces; scrap-drop events; scrap melting completion
- time; thermal contours after end-of-arcing; the extent and duration of slag foaming; and details of the tapping operation (including the size of the hot heel), have been demonstrated and these direct online
- views of operations inside the furnace to provide the operator with improved control of the process.
Compared with other solutions the EMLI-FBL has the following advantages:

- Once the system is installed, the bath level measurements are made automatically at no extra cost.
- Several measurements are automatically performed during each heat, providing true and repeatable results.
- Enhanced safety as it does not require the operators to perform extra procedures and expose themselves to danger in order to collect a bath measurement.

Source: Electromagnetic bath level measurement system improves EAF melting process control, AISTech 2014
Conclusions

- Research and innovation is a key driver for energy and resource-efficient EAF technology.
- Improved process control requires more sensor and measurement data.
- Until now, only few RFCS projects were directly related to sensors and measurement techniques for the EAF.
- Continuous measurement allows further improved understanding of actual process conditions also during fast processes such as heating or mixing.
- Online monitoring and real time sensors for improved EAF control is a requirement for future steelmaking.
- As in daily life, sensors become increasingly important to supply real time process information.
Thank you very much for your attention!

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