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A WINDOW INTO THE ELECTRIC ARC FURNACE, A CONTINUOUS TEMPERATURE SENSOR MEASURING THE COMPLETE FURNACE CYCLE

WGLĄD DO ELEKTRYCZNEGO PIECA ŁUKOWEGO – CIĄGŁY POMIAR TEMPERATURY ZA POMOCĄ SONDY TEMPERATUROWEJ W CAŁYM CYKLU WYTOPU

Temperature measurement and control are critical factors in the operation of a modern electric arc furnace. This paper outlines the first stages in the development of a temperature measuring system, which shows the promise of being able to accurately measure the temperature of the steel in the furnace for the whole furnace cycle. It is envisaged that the sensor will bring improvement in productivity, refractory lifetime and operator safety.
Keywords: Electric Arc Furnace, EAF, Temperature measurement

Pomiar oraz sterowanie temperaturą są czynnikami mającymi największe znaczenie w działaniu nowoczesnego elektrycznego pieca łukowego. W artykule opisano pierwszy etap prac nad systemem pomiaru temperatur, który byłby w stanie dokładnie zmierzyć temperaturę stali w piecu podczas całego cyklu produkcyjnego. Przewiduje się, że czujnik w znacznym stopniu poprawi wydajność, trwałość wyłożenia ogniotrwałego oraz bezpieczeństwo pracy.

1. Introduction

Heraeus Electro Nite has been manufacturing high quality sensors for use in the molten metals industry for 45 years. The company has brought many technological innovations to the steel industry over this period of time which range from high quality soluble oxygen measurement systems, hydrogen measurement systems through to continuous temperature measurement for the end part of the steelmaking process, the tundish.

These innovations have all followed a similar development route where Heraeus engineers work in close collaboration with steel plant personnel to identify the need for process improvements which can be brought about by improving measuring technologies.

A superb example of the benefits achievable by following this approach are seen after the launch of the Heraeus CasTemp® system for continuously measuring the temperature of the steel in the tundish of the continuous casting plant. Initially the take up of continuous sensors by the steel industry was slow due to the fact that steel plant personnel already had dip systems to take spot measurements of the steel in the tundish; also a number of supplier offered a top mounted continuous temperature measuring sensor. This lead the steel maker to believe that tundish temperature measurement was actually taken care of by using one of these existing systems so improvements were not necessary and the criteria for system adoption was simply best value to support current practice.

In hindsight this could not be further from the truth where a thorough survey showed that conventional temperature measurement systems for the tundish do not lead to the most optimised conditions, there are still relatively large temperature variations between ladles and that the available systems suffered from numerous application problems that affect availability of the measurement and also how the measurement relates to the actual temperature of the steel flowing from the tundish to the mould.

With these findings a sensor was developed which is applied through the tundish wall in close proximity to the tundish outlet nozzle, this avoids all the sensor handling and operator safety issues, as well as slag attack on the sensor and the inability to measure at low tundish levels. The result is a dramatic improvement in

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accurate measurement availability which has led some of the advanced steel makers to reduce tundish superheat by up to 5˚C, and also reduce the incidence of "Breakouts" and "Freeze offs". The confirmation of this need to advance measuring systems is shown clearly by the savings actually measured by two very large and efficient steel plants in Germany and the USA. The German steel plant is reporting that CasTemp® is saving €/0.33/Tonne by allowing the superheat to be reduced and by avoiding unplanned machine stoppages and the American plant has reported an overall saving of $7 Million in the first year of operation.

This development paved the way to industrially measure the temperature of steel continuously through the refractory wall of the process vessel. The next question was which part of the steel making process needs or would benefit the most from a continuous sensor, the answer for various reasons returned as the Electric Arc Furnace.

2. The need in the Electric Arc Furnace

The EAF has been the steel making process which has undergone the most development over the last few decades due to the growth of Mini Mill's worldwide. Significant developments like slag foaming, Consteel, application of Co-jet burners as well as growth in furnace size and power capabilities have dramatically improved the efficiency and productivity of these furnaces however temperature measurement, a critical parameter remains the same, with dip thermocouples being the standard.

These furnace developments have all contributed to creating a more dynamic thermal environment where access to the steel bath becomes more restricted by deep slag cover, intense radiation due to the arc and the burners. These factors also contribute to increase the safety risk for the operators who are responsible for taking the temperature measurements.

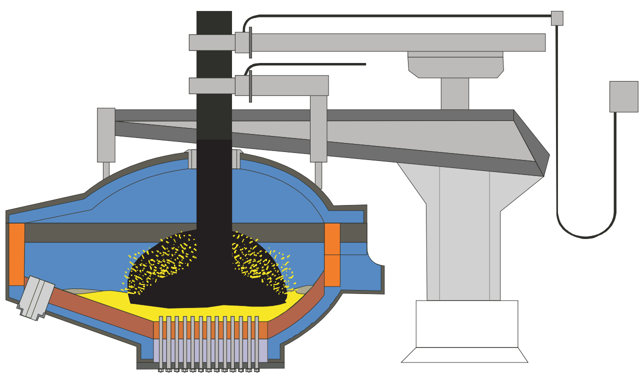

Fig. 1. A typical DC Consteel Arc Furnace

The drawing shows a typical DC electric arc furnace where tap to tap times for 150-200 Tonnes of 30 minutes are possible with power inputs of in access 180 MW/hr. To assess the need Heraeus engineers also monitored a number of furnaces worldwide for a number of days each to look at the temperature measuring performance as well as the process stability. Although the process has seen many developments over the years the EAF remains a highly energy dependent process where efficiency improvements from any part of the process will be welcomed by the steel maker, Figure 2 shows a typical furnace energy balance.

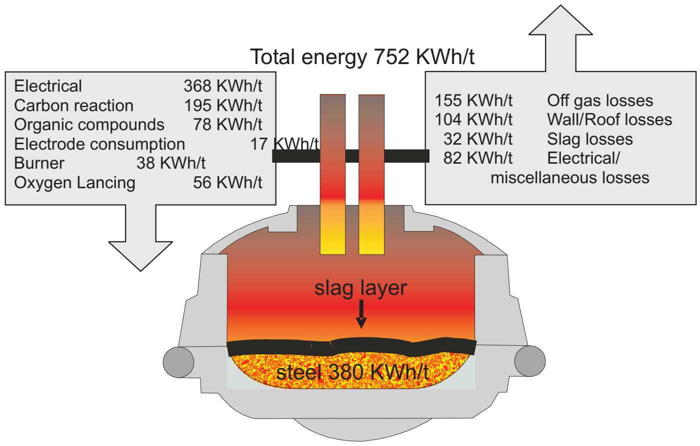

Fig. 2. A typical energy balance for EAF

Figure 3 highlights that the process although working well at these highly efficient plants could be much better.

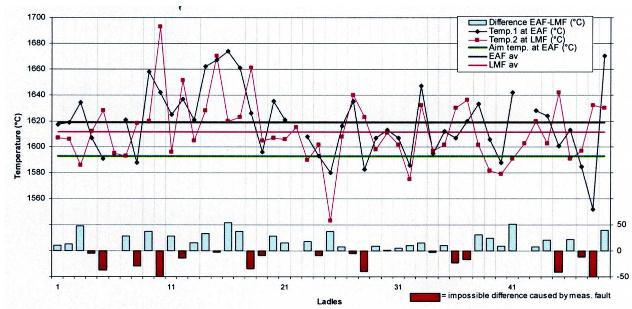

Fig. 3. Working temperature of EAF and LMF

It's clear to see that in theory the steel ladle should always arrive at the ladle furnace slightly colder than it leaves the melting furnace, it is simply not possible that as shown in the graph ladles can be hotter on arrival at the ladle furnace than they were when they were tapped. The reasons for these differences are thought to be directly attributed to the difficulty in measuring the temperature of the steel bath in the EAF due to the harsh thermal environment and the deep foamed slag that covers the melt. Immersion thermocouples are extremely accurate (+3, -0˚C) calibrated at 1554˚C, which is the melting temperature of pure palladium, however the sensor needs a clean immersion where the cap protecting the

Platinum/Rhodium thermocouple from slag melts away from the sensor and allows the thermocouple to come into direct uncontaminated contact with the liquid steel to be measured.

3. Sensor system

The need was clearly identified so research was carried out to identify the sensor technology that could provide the best chance of delivering a viable solution to measure the melt temperature of the steel in the EAF process. Previous attempts have been made to achieve this goal with various technologies such as Infra Red cameras looking directly into the furnace or even through the burners, continuous thermocouples either in the furnace bricks or inserted into the steel from the furnace roof; to exotic systems such as acoustic noise which predicts the furnace temperature by measuring the acoustic properties of the arc which vary with furnace temperature. In reality these systems all work but as yet they have not proved to "go the extra mile" and achieve the improvement over the current "state of the art" by delivering the accuracy required at a reasonable cost.

From previous work the sensor needs to satisfy the following criteria:

- Be in direct contact with the steel in the furnace for the maximum period of time.
- Be in thermal equilibrium with the melt at the time when the furnace is ready to tap.
- Not be damaged by normal furnace operations i.e. loading scrap, slag corrosion, etc.

The system was then defined as having to be located in the hearth area where it would be permanently submerged under the furnace "heel" in as close a proximity to the tap hole so the bath could be measured even during tapping. These requirements dictated that a sensor that would be flush with the furnace wall so would also be a "thro wall" design similar to the CasTemp®.

These requirements dictated that the sensor would need to be based on optical pyrometry as previous work had shown that thermocouples embedded in the furnace wall are not in sufficient thermal equilibrium with the melt to be representative of the melt.

The basic components of an optical pyrometer system are shown in figure 4, where a sighting tube or light guide is used to transmit the light emitted by the steel to an infra red receiver. The infra red receiver takes in a known wavelength of infra red radiation and measures the intensity of the said radiation. From this the temperature of the body emitting the radiation can be calculated. An important point is that by maintaining the direct contact of the sighting tube with the melt then the infra red enters the sensor under "black body" conditions this eliminates emissivity issues which are a major disadvantage to optical temperature measuring systems.

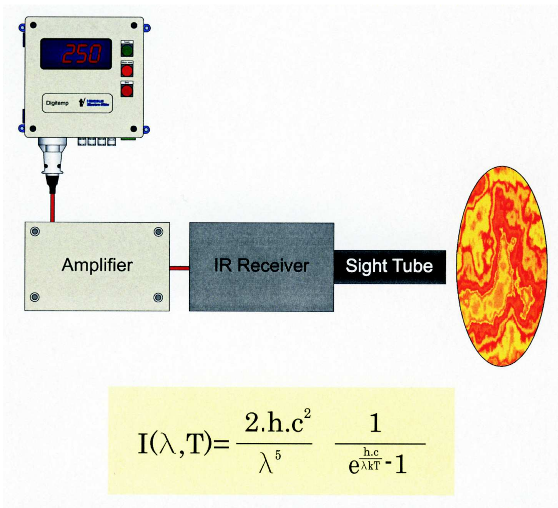

Fig. 4. The basic components of an optical pyrometer system

The early stages of the development concentrated on manufacturing a "tough" enough system to cope with the conditions directly under the EAF where temperatures are very high and the radiant heat from furnace tapping creates major problems for cables and instrumentation. Another problem was overcoming the effects of electro-magnetic radiation on sensitive electrical systems within the pyrometer.

Figure 5 shows a typical output from one heat of a large DC EAF, the sensor stays in contact with the steel of the furnace heal indicating that the heal freezes as the temperature falls below the liquidus of the steel. The interesting fact is that the sensor clearly identifies the point when the metal that the sensor is directly contacting becomes liquid and begins to heat rapidly due to the fact that the energy being supplied to the furnace is only heating liquid steel and at that point in the energy supplied by the furnace is not being used to overcome latent heat.

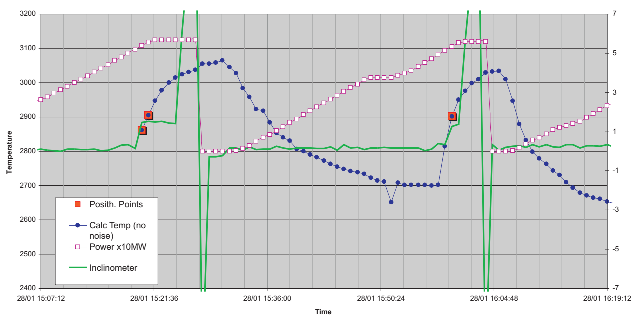

Fig. 5. A typical output from one heat of a large DC EAF

Figure 5 shows temperatures from immersion thermocouples to check and calibrate the newly developed optical system that are ±5°C of the temperature measured.

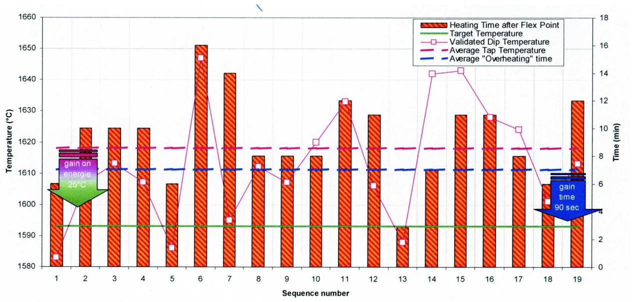

Fig. 6. Relating over-temperature and heating time

The sensor output shows a clear inflexion point on every heat where the steel in contact with the sensor undergoes a state change from solid to liquid which then shows as rapid superheating of the steel. Figure 6 relates the energy input after the inflection point to the temperature at tap. It can be seen that on most heats there is a relationship however this doesn't appear strong enough to be a control parameter. It is believed that the differences are related to the heel size as it goes liquid and how the remaining scrap melts into the heel. Figure 6 also shows how a typical efficient operation still maintains a significant margin over the optimum target temperature due mainly to difficulties in acquiring a high quality measurement in a harsh and dynamic environment.

4. Conclusions

To date the development team has managed to achieve these accurate results for a few days of operation of a rebuilt furnace however the target, the full furnace campaign is still a long way from the current performance. The current developments are focusing on materials and sensor construction to improve the longevity and achieve the goal.

If indeed this goal is achieved then the sensor will allow the EAF user to avoid overheating the steel past the optimum point which will save energy and reduce refractory wear however the largest saving comes from reducing the tap to tap time by seconds and possibly minutes by identifying the optimum tapping temperature thus allowing the steelmaker to increase productivity.

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