Milestones of process control in ferrous metallurgy. Past, today and future

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The paper presents an overview of the state-of-the-art sensing techniques in Hot Metal and liquid steel, and gives an outlook to innovation "ante portas" such as sensor technologies for on-line phosphorus measurement, cleanliness control and smart refractories.

INTRODUCTION

Control techniques in metallurgical plants are not new, just the methods have changed in time from the industrial revolution through the turn of the century at 1900 and commencing mass production till today's new millennium where quantity is increasingly being replaced by striving for quality. What happened to the metallurgical sector is similar to other industries. There have always been calculators and communication. But the methods have changed. The Chinese used the Abacus, shifting wooden balls on strings. Today there are computers. On the Canary Islands the early settlers used "Il Silvo", whistling for communication over long distances. Today there's e-mail.
I remember my time in the electric shop in the early 80's the older foremen talking about their experience when guessing carbon from spoon sampled steel on the shop floor, furnace temperature from off-gas flame length and phosphorous from slag boiling.
The furnace control room was full of engineers and operators by that time. Today it is frequently just one man operating the "one-man-furnace". He uses manipulators and state of the art sensing technique to deliver liquid steel to ladle metallurgical treatment or caster. He has to do the same job as the whole experienced team before. And he can...he has got good aids: engineering equipment and state of the art control techniques. The coming up sensing technology had found its way. Let us have a look to important milestones of the past, today, and the future.

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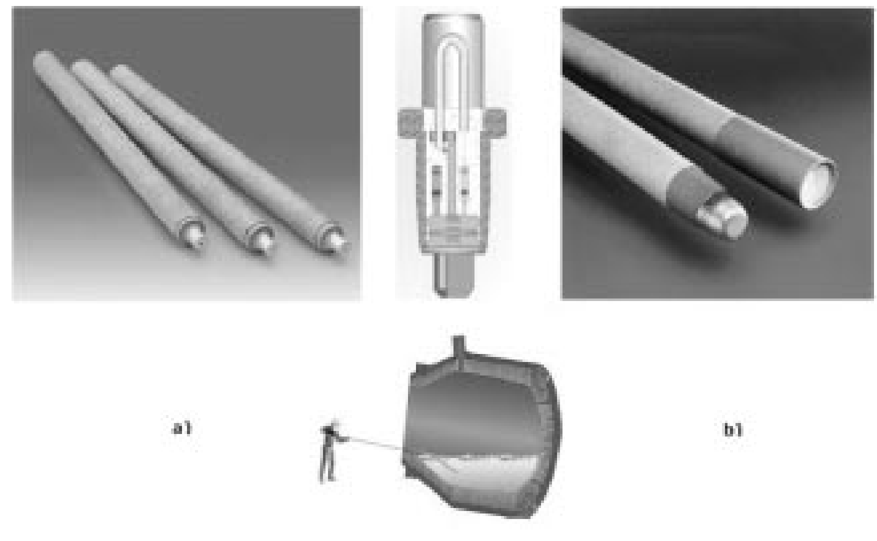

Fig. 1a: The 60's - Temperature measurement in liquid iron & steel using dip thermocouples.For 1a) Bath temperature and 1b) Liquidus ((%C) –measurement.

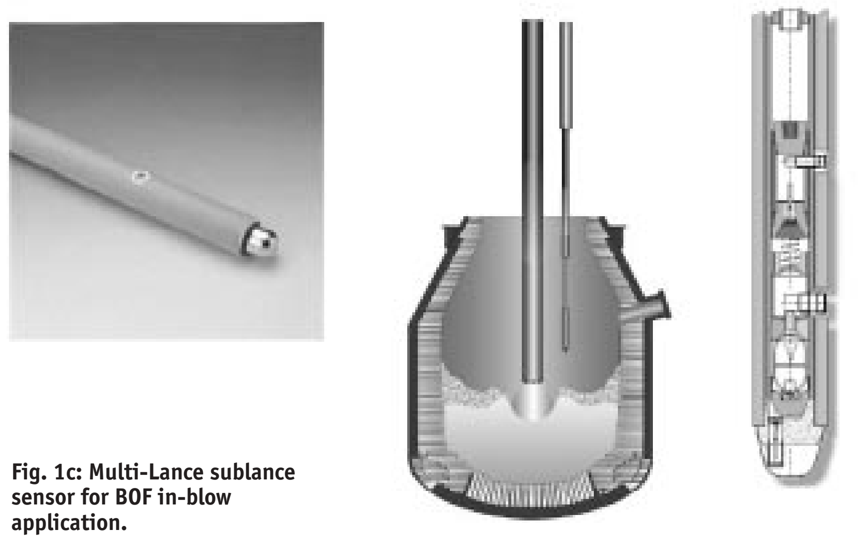

Fig. 1c: Multi-Lance sublance sensor for BOF in-blow application.

A LOOK BACK - THE PAST. ARLY SENSORS STILL YOUNG

Early immersion sensors – for temperature and oxygen measurement

Thermocouples set on a paper tube and connected to an immersion lance were the first disposable sensors. Accurate temperature control in liquid steel operation is still most important - Fig. 1a.
Fig. 1b shows modern so-called Tap Tip sensors for simultaneous bath temperature and Liquidus (%C) control. Thermal Analysis or Thermal Arrest is as well an early sensing method to precisely control the dissolved carbon content, the most

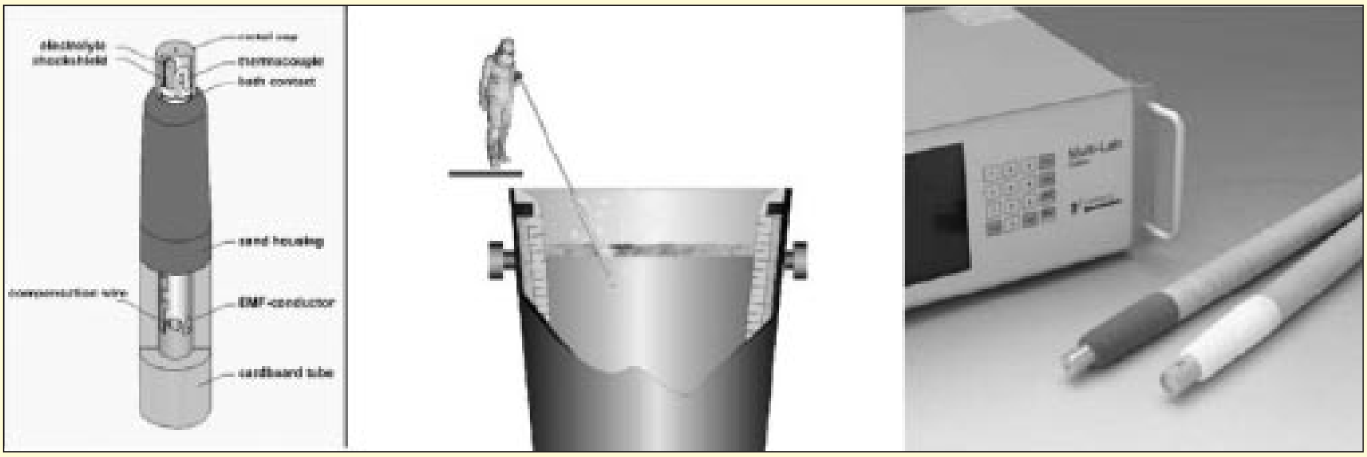

Fig. 1d: The 70's - Oxygen measurement for oxidation/deoxidation control, plus carbon and aluminum calculation.

important element in ferrous metallurgy. Based on these 2 measurements, bath temperature and thermal arrest a new family of sensors was started already in1967, the combined Multi-Lance sensor or sublance probe for BOF control, Fig. 1c: The early versions of sublance probes were still lacking a sample chamber; today most major BOF shops make use of a sublance system, about 100 systems are operational worldwide.
The following decade created a new generation of sensors, the oxygen sensors based on solid electrolyte technology. It became possible to measure the steel's oxygen activity on-line. Oxidation and refining processes came under control.
Being in combination with a thermocouple the measured cell voltage can be con-

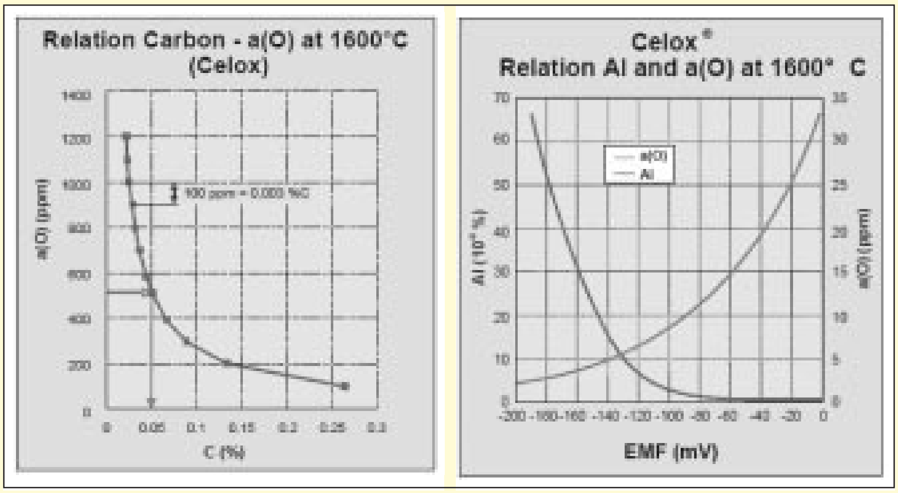

Fig. 1e: Relations oxygen activity vs. %carbon and %Al vs. EMF.

Fig. 2: The late 80's and 90's - the gas sensors Hydris and Nitris.

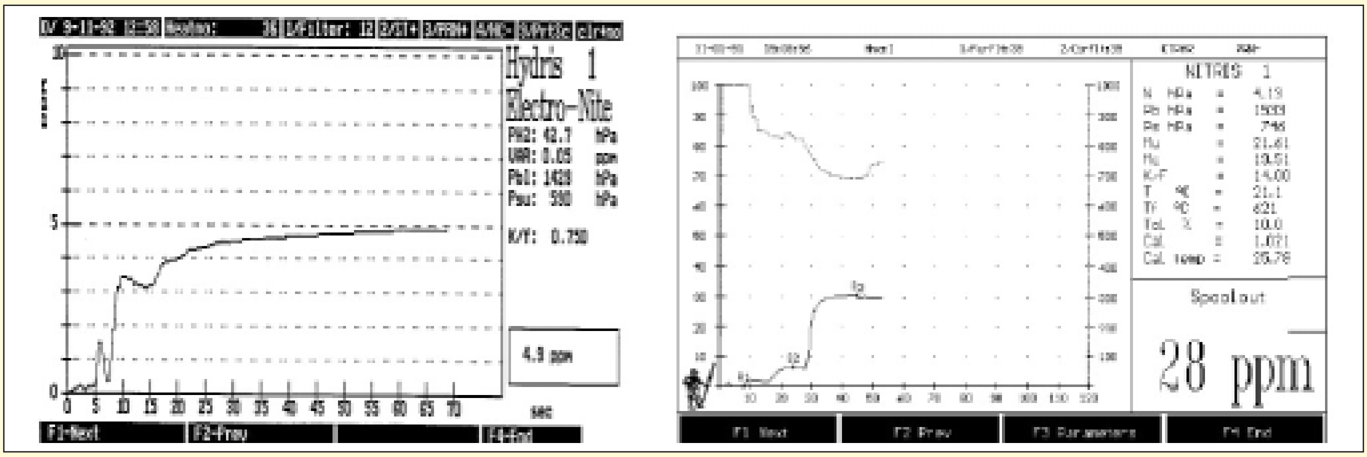

Fig. 3: Hydris and Nitris measurement traces.

verted to oxygen. From this oxygen affine elements of dynamic change like carbon in oxidizing stages and aluminum in killed steel are calculated. Fast growing use of oxygen gas and thus faster and faster processes made the oxygen sensors a tremendous worldwide success.

Vapor pressure sensors

Fig. 2 and 3 show the two Heraeus Electro-Nite sisters Hydris and Nitris for on-line hydrogen and nitrogen measurement. Vapor pressure is the third used sensing method in liquid metals. Based on the equilibrium constant between gas phase and liquid steel and Sieverts' law, it is possible to correlate the dissolved gases to a known certified gas composition. Measurement time is in the range of 1 minute, precision equal to or better than LECO analyzers. Hydris is today the world standard for hydrogen analysis and certification.

Fig. 4: Contitherm application and sensor construction.

THE PRESENT TOP 3 CONTINUOUS TEMPERATURE CONTROL, SLAG - AND HOT METAL SENSORS CAME ON STREAM

Continuous temperature measurement

Long desired and finally made, a continuous temperature sensor for continuous casting. 2 things that go together well. Contitherm is used in the tundish typically over 24hrs with a precision even somewhat better than best dip thermocouples from the same maker.
Fig. 4 shows the application and the Contitherm construction.

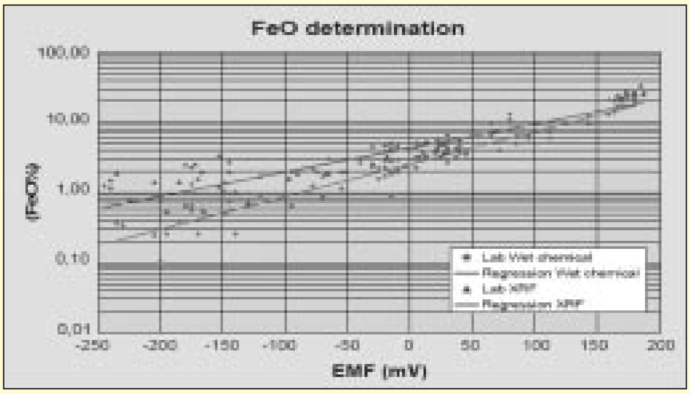

Fig. 5: Correlation %FeO – EMF.

Slag oxygen sensor in ladle metallurgy

On-line slag control has always been a sealed book for the steelmaker. A variation of the electrochemical method in steel is used to control oxygen in ferrous slags.
Traditional methods for slag oxygen control have all been off-line until now, as based on sampling methods followed by downstream lab sample analysis. Today X-ray spectrometry is the industrial standard whereas wet analysis, offering a higher precision but being time consumptive, is applied here and there as an exception.
The electrochemical slag sensor especially plays its strength in the low FeO-range where sample analysis suffers from accuracy, Fig. 5.

Applications

Celox SLAC is compatible with standard hardware series not requiring special investment. Using dedicated software, a single immersion lance is sufficient to run thermocouple, steel oxygen and slag oxygen readings. The measurement procedure follows the standard practice of probe immersion into liquid steel. Going down the sensor's measuring head passes through the ladle top slag and collects a small amount of the molten slag after which a thin slag layer adheres to the zirconia solid electrolyte tube long enough to obtain a measurement result, Fig. 6.
Typical applications for Celox SlaC in the ladle are control of

- Slag carry-over during BOF or EAF during tapping
- Desulphurization
- Al fade and trim
- Steel cleanliness and nozzle clogging prediction.

Sulphur and silicon control in hot metal

Sulphur and silicon sensors in Hot Metal application save time, desulphurizing ma-

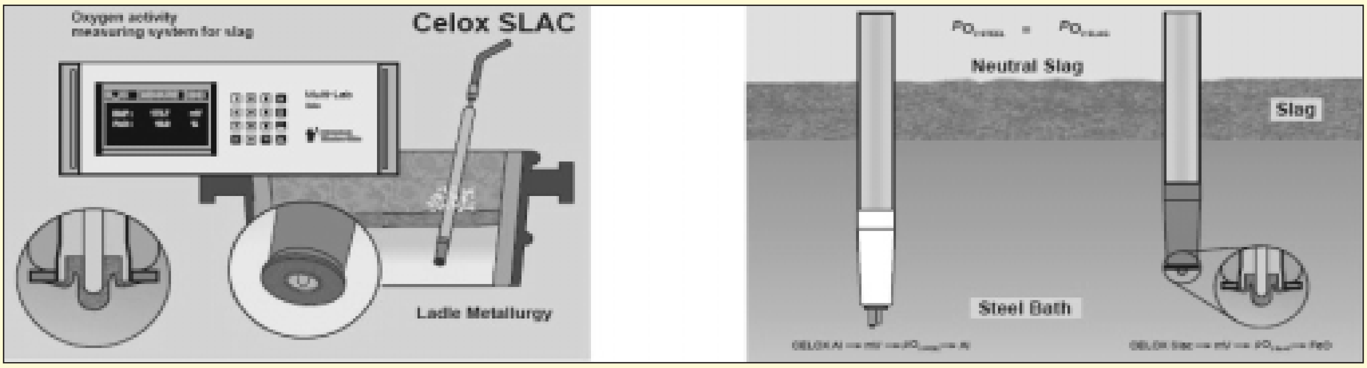

Fig. 6: Measuring system Celox SlaC.

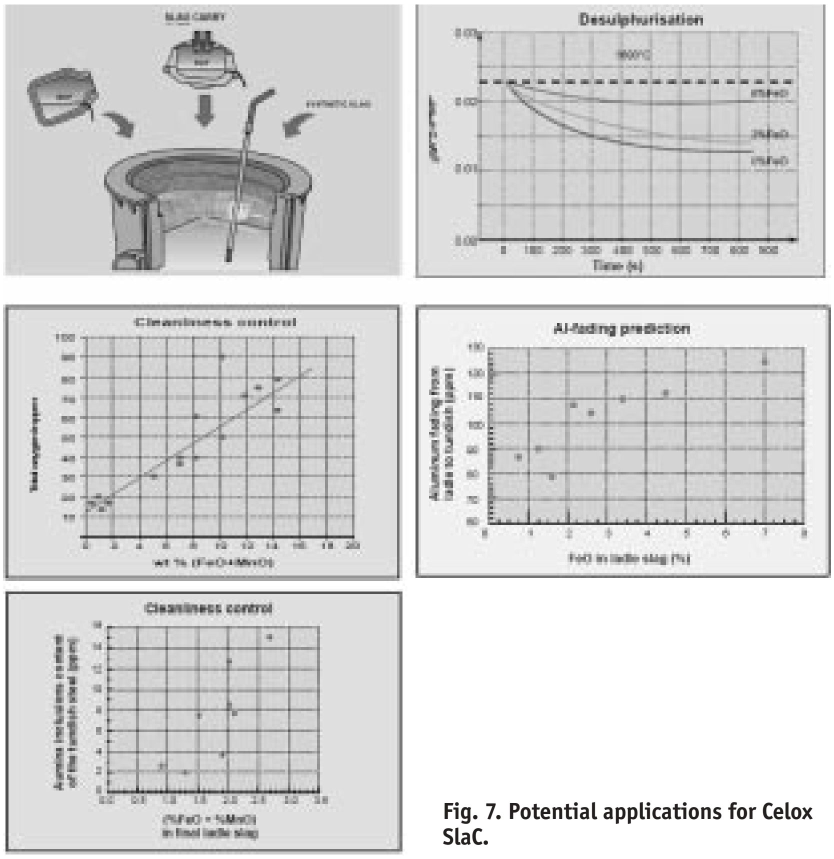

Fig. 7. Potential applications for Celox SlaC.

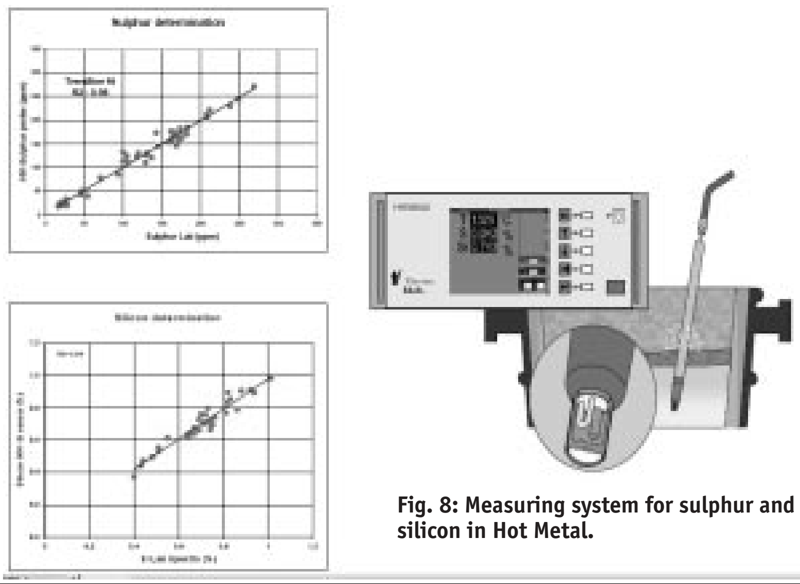

Fig. 8: Measuring system for sulphur and silicon in Hot Metal.

terial and assist in optimizing product flow between Hot Metal treatment and steel shop. The lab is released from extra work. Euro 40 per 0.001% desulph in the range under 0.010% sulphur is a typical cost for a 200ton heat, a cost that is substantial and savings in the range of a Euro 1000 per day are realistic, as practice with the new system in a major German BOF shop has shown.

A LOOK TO THE FUTURE - ON-LINE PHOSPHOROUS MEASUREMENT IN BOF's, IN-SITU CLEANLINESS MEASUREMENT IN LIQUID STATE, AND SMART REFRACTORY (?)

Multi-Lance@function for on-line slag and phosphorous control in BOF steelmaking

Reduced BOF quick tap rates due to stringent phosphorous specs could be largely history. A new series of @function sublance sensors are believed to enable BOF slag control and associated phosphorous calculation. Typically 10 – 15% of all heats may not be quick-tapped due to waiting for the phosphorous result from the sublance or turn down sample. This, on average, reduces output by half a heat per day or more dependent on steel grade mix. Phosphorous calculation will be based on a Multi-Lance@function TSO-style sublance sensor and additional data computed in an expert system: %P = f (T and aO in steel, T and aO in slag, dynamic CO-product change and top slag amount.

On-line cleanliness control

It has long been on metallurgists' wish list to have a look into the liquid steel to predict the future of that heat in terms of castablity, cleanliness and customers' satisfaction. A hopeless desire up to now, and the quality control people had a hard time to satisfy this need by sample preparation and downstream optical inspection. All this information obtained from sample is however "post mortem", after the death when steel is cast and maybe already rolled and further processed. A late decision form the quality department "sorry guys, scrap" may cost a fortune.

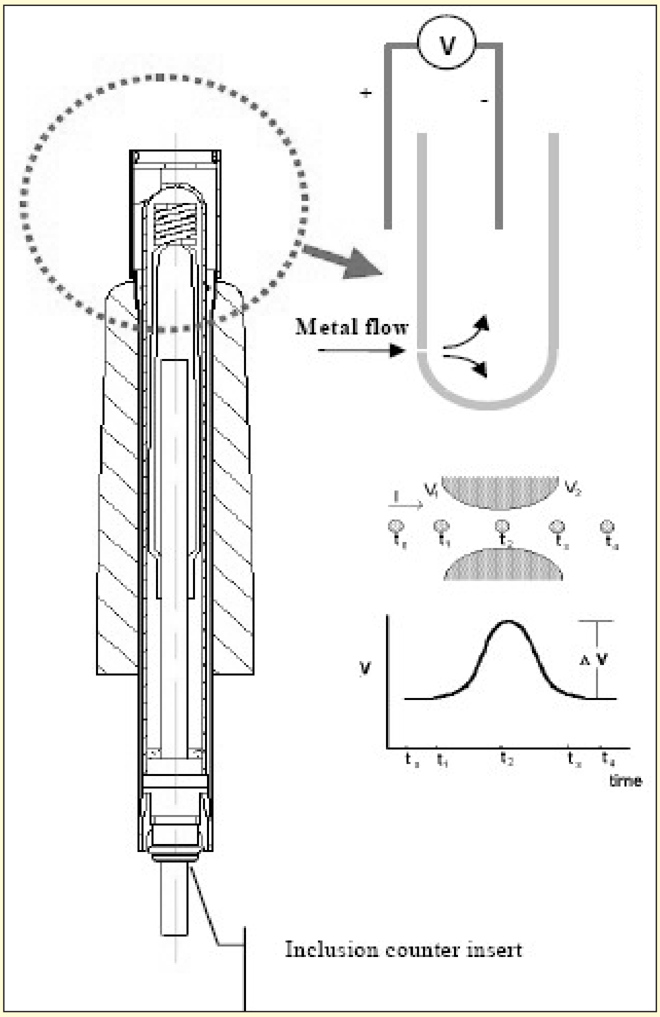

Fig. 9: Functional principle of the Inclusion Counter.

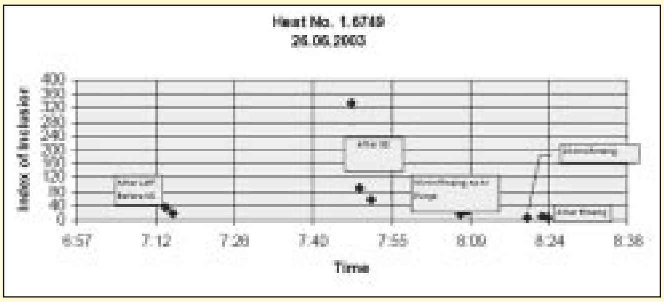

Fig.10: Inclusion Counter measurements in ladle metallurgy.

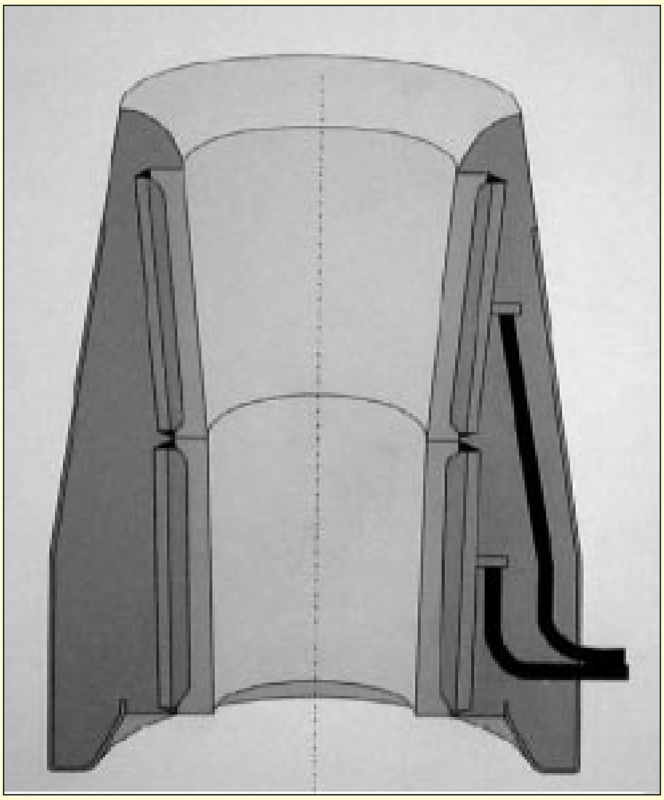

Fig. 11: Functional nozzle.

A new sensing approach may bring the change. The so-called Inclusion Counter is under industrial testing to simultaneously count and size non-metallic particles in liquid steel, in ladle and tundish. At least in ladle application this can lead to an additional treatment to clean up the steel or to modify non-metallic particles prior to casting. The functional principle is shown in Fig. 9.

Inclusion counter insert A vacuum is applied that results in drawing metal through the probe orifice and into the electrically isolated sampling chamber. Two current carrying electrodes are located on each side of this chamber.

As a non-conductive particle enters the orifice it displaces electrically conducting metal increasing the resistance. A voltage spike is measured in the constant current circuit between the two electrodes.

Fig. 10 shows a result of various Inclusion Counter measurements at different ladle treatment stages in a German steel shop obtained last year. It is very obvious that the "Cleanliness Index" changes in the course of the treatment. Highest values are recorded directly after tank degassing.

Smart nozzles

Refractory is stupid! Well, times change and so may functional refractory parts. Like tundish nozzles. Today nozzles for shrouded continuous casting are isostatically pressed black refractory parts and nozzle clogging is a frequent problem. This growing build-up caused by agglomerated non-metallic particles reduces the open pouring section, hampers steel flow and limits the sequence length. Often pieces of clog material come lose and cause a quality problem, if caught in the strand.

In future flow control refractory might change from a stupid piece of refractory to a smart functional high-tech product. Fig. 11 shows what is already on the horizon. The concept is to combine refractoriness with electrical function. Make it smart. By means of applying an electrical voltage on special refractory materials it is possible to heat them, influence the wetting conditions or to pump oxygen from on side of the nozzle to the other using the principle of an electrochemical cell.

SUMMARY

I think it is evident that sensing techniques in times have first enabled and then pushed forward process automation to today's state of the art steelmaking. Most sensors are being used in ladle metallurgy but a shift towards the quality sensitive continuous casting process is already predictable.

The new techniques are believed to further cut operational cost and downstream quality control efforts. New sensors will preventively act smart whenever out of specification events happen, e.g. in cleanliness control and refractory function.

Today's precision sensors and future new sensing technologies will accompany the steelmaker towards a no-event production.

Developers of sensors for application in molten metals are working on sensors to function on mouse-click, moving expertise from grandfather through father to son. Let us look forward to the next milestone in metallurgical control.