Implementation Of An Automated Drop In Sensor System At Rautaruukki Steel Raahe Steel Works

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I. Introduction

Founded in 1960, Rautaruukki OYJ is the largest Steel Company in the Nordic countries and the leading producer of flat rolled products in the region. Raahe Steel Works (RSW) is part of Rautaruukki OYJ concern. RSW produces flat rolled plate, sheet and coil, at an annual production rate of 2.5 million tonnes. The business plan calls for a production increase of more than 10%, totaling 2.8 million tonnes, by the year 2000.

RSW has two (2) blast furnaces, three (3) 120 tonnes combined blow BOF converters with inert gas stirring feeding, five (5) continuous casting machines. During 1998, a new ladle furnace and vacuum degasser were commissioned.

Two of three converters are working simultaneously, while the third is being relined. One lining campaign lasts about 1700 heats. The production rate, using 2 converters, is 1900 heats/month. Tap-to-tap time is about 40 minutes, without the aid of direct tapping or sublance.

II. Automatic Drop In Sensor System Rational

RSW is planning to increase its raw steel production to 2.8 million tonnes, as shown in Fig. 1.

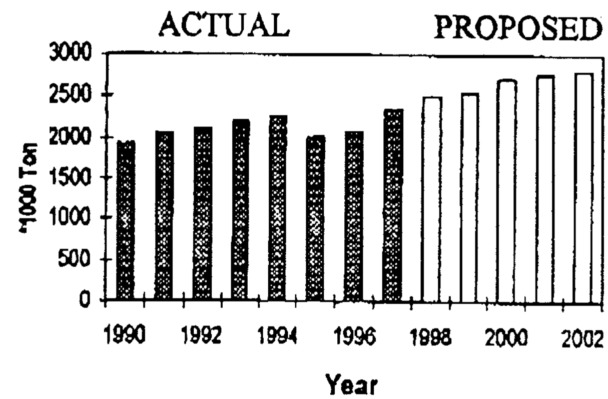

Figure 1. Raw Steel Production of Raahe Steel Works

At this production level, the BOF shop is the bottleneck. A normal turndown sampling BOF process time line is shown in Figure 2. An interval of 9.5 minutes is required to verify the process with respect to temperature, carbon content, and chemistry. A reblow would substantially increase this time interval. One possibility to increase production is implementation of a direct tapping process, currently utilized by many steel plants, worldwide.

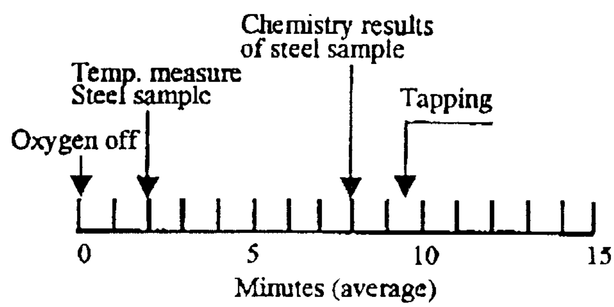

Figure 2. Normal BOF process timeline.

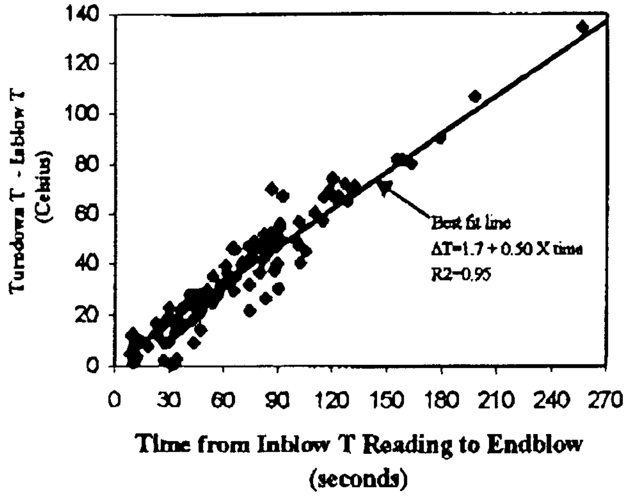

Figure 11: Relationship of temperature pickup (Δ Temp) versus elapsed blow time (Δ Time). Note high degree of correlation.

This relationship is quite linear since the during blow sensor was dropped at about the same time from the calculated endpoint of the blow. Also, only heats without coolant additions were selected for this analysis. There are indications that the factor of temperature pickup with blow time is non-linear at greater time intervals from the endpoint of blow. This is probably due to higher carbon content in the bath, and a greater effectiveness of te ɔerature rise per unit of oxygen blown.

VII. Future Work

Direct Tapping Practice Scenario

A practice utilizing the linear temperature pickup function would require the operator (or computer model) to adjust the blow oxygen (or add coolant) based on the expected turndown temperature resulting from the inblow drop in sensor actual temperature. The endpoint TO sensor verifies that the proper temperature has been achieved and that the carbon content is in the expected range. Other critical elements can be calculated from process data. If all process parameters are at statistically acceptable levels, the heat may be direct tapped. Slight alloy and temperature adjustments may be necessary downstream at the LMF.

Automatic Drop In System Improvements

As with any new or emerging technology, the mechanics, automation interface, and process control application of the system are still evolving. As of this writing, plans are being considered for a larger machine, capable of handling 5 x 15 or 75 sensors. In addition, the automation of data capture and process control interconnection are expanding out of the "Beta" prototype stage.

This automated drop in sensor system, as integrated into Raahe Steel Work's steelmaking process control scenario, can provide critical steelmaking data in real time. This information can be used to improve the understanding of the dynamic steelmaking process and enable direct tapping of the BOF.

Acknowledgements

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Historically, direct tapping is achieved utilizing a sublance system, which includes sampling during the blow. At RSW, the investment in sublance would be quite large for the 3 x 120 MT vessel shop. An alternative solution was sought for the sublance. This new system must be highly automated, be capable of inserting temperature (T) and temperature/oxygen (TO) sensors during and after blow, and fit budget requirements. The new Automated Drop In Sensor System (ADSS) grew out of a collaboration between RSW and Heraeus Flectro-Nite.

The ADSS has the potential to measure temperature and oxygen during blow, or at the endpoint, with lower capital investment and disruption to the BOF shop operation than sublance. Utilizing the CxO product relationship to calculate the carbon level of the steel from the oxygen activity is a fast and direct empirical method for low carbon steels (%C < 0.12).

Figure 3 depicts a plan for direct tapping. It calls for the use of a Temperature drop in sensor (T) during blow, followed by a Temperature/Oxygen sensor (TO) at the endpoint. The during blow T sensor is used to make fine-tune adjustments to the heat to keep the process on track.

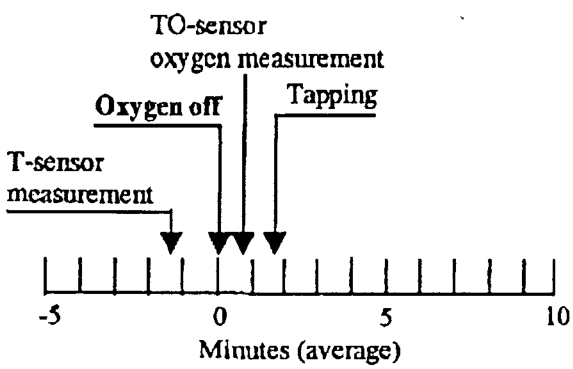

Figure 3: Planned direct tapping BOF process timeline utilizing T during and TO sensor at endpoint of blow.

The endpoint TO sensor verifies that the temperature endpoint is reached. Also, through the CxO relationship, the bath carbon level is determined and the steel can be direct tapped without turndown sampling.

III. Description of Automatic Drop In Sensor System

General

The ADSS contains three (3) fundamental parts:

(1) Expendable drop in sensors,
(2) Instrumentation for signal interpretation and display, and
(3) Dedicated automatic manipulator to drop the sensors into the BOF vessel during and/or after the oxygen blow cycle.

The manipulator and sensors are designed to obtain fast and reliable measurements of bath temperature and/or oxygen level. These critical steelmaking process control parameters can be determined on demand by the operator. Due to fast manipulator cycle times, during blow measurements can be obtained up to 15 seconds before the programmed endpoint of the heat.

The ADSS enables automated BOF measurements from the operator console in the control pulpit. The manipulator operates under PLC control, releasing the chosen sensor at the right moment. The signal interpretation instrumentation (Figure 4) is triggered by the same PLC. Finally, the PLC disconnects the used sensor cable from the contacting system and transports the next sensor into the drop position. The ADSS can be customized to hold any amount of sensors, taking into account the local needs and space possibilities.

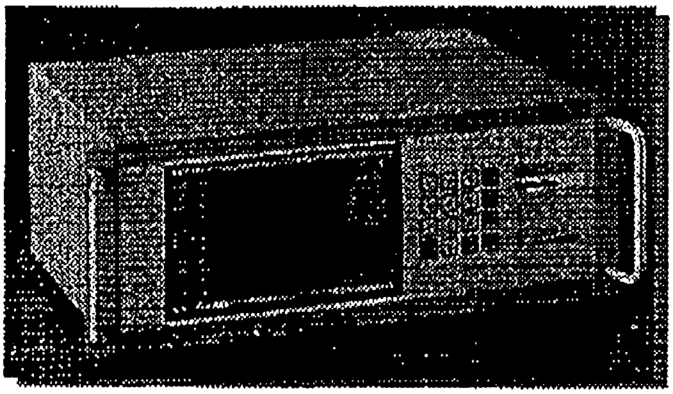

Fig 4: Photo of signal interpretation Instrumentation

Automatic Drop In Sensor Types

Two types of Automatic Drop In Sensors are used by RSW:

(1) Temperature (T) to measure bath temperature with a Type B thermocouple (T/C).

(2) Temperature/Oxygen (TO) measures bath temperature as above, and the oxygen activity using a zirconia electrochemical cell.

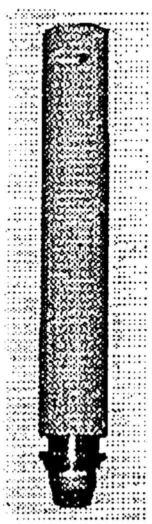

Figure 5: The Automatic Drop In Sensor

The sensor consists of the following parts as shown in Fig 5:

1) The Measuring Head

The steel measuring head is designed to penetrate through the slag layer into the molten steel bath. The 3.3-kg weight is needed to reach a sufficient velocity in the drop chute. The necessary measuring elements are contained within the steelhead. They are covered by a thick slag cap, which protects them from contamination during the slag penetration. The head shape is designed to enable the automatic head release by the manipulator.

2) The Connection Cable

The connection cable conducts the measuring signals to the instrumentation via the connector. The cable is wrapped within a paper tube, in such a way that combines maximum cable length while minimizing sensor length. A 25-m length is required to drop the measuring head into the steel bath in the vessel from the manipulator position at RSW.

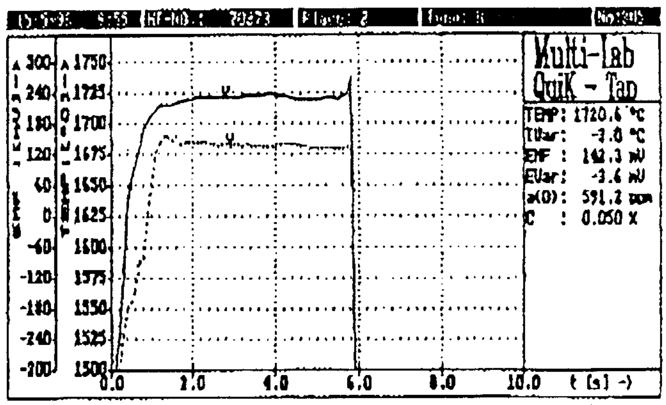

Fig 6: Temperature/Oxygen Signal traces; Note quick response time.

Immersion times of 6 to 7 seconds are usually sufficient to obtain stable signal levels for both T and TO sensors. Fig. 6 is an output signal from a TO sensor. The "tick" marks indicate where the instrumentation captures the reading in less than 5 seconds after the start of the measurement.

3) The Connection System

The connection cable is fixed to a male connector which is centered in the rear of the sensor cartridge assembly. A molded plastic ring keeps the connector in a fixed position, allowing proper alignment in the manipulator. Each cartridge contains a paper seal to avoid dirt contamination during storage and handling of the sensor.

Automatic Drop In Sensor Manipulator

The ADSS Manipulator is a dedicated handling system for the sensors. It combines fully automated operation with a sufficient amount of available sensors in a removable storage cassette. The self-contained manipulator, shown in Fig 7, features quick-disconnect fittings to allow it to be moved quickly. The major components are described below.

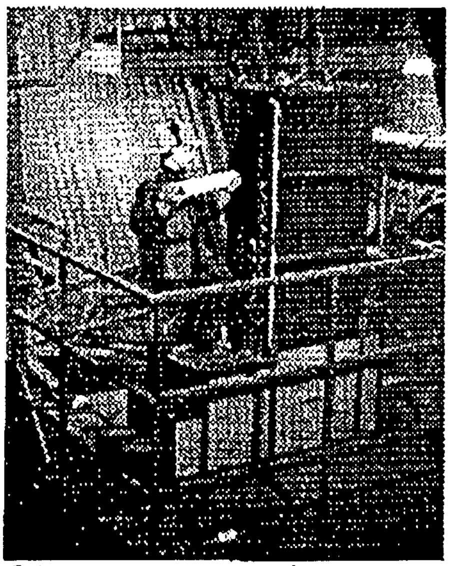

Figure 7: Photo of the Automatic Drop In Sensor Manipulator

(1) The Sensor Storage Cassette

A number of sensors are stored in different rows of a removable cassette which allows offsite loading. Each is filled with one type of sensor (T or TO). The cassette height determines the total amount of available sensors and is limited by the available space above the BOF vessel. The standard quantity is 15 sensors, loaded on top of each other, in each row. Cassettes may vary from 3 to 5 rows, so that maximum quantity is 75 sensors per cassette.

(2) The Manipulator Mechanism

The storage cassette is placed on the manipulator section of the machine. The manipulator contains all necessary transfer equipment for sensor manipulation from the storage cassette into the "ready-to-drop" position. All mechanical movements are pneumatically driven by nitrogen actuated cylinders.

The Measurement Cycle

Each manipulator row works independently, so that each row has a sensor in the "ready-to-drop" position. The cycle time from "ready-to-drop" until completed reading is on the order of 15 seconds. The total cycle time to have a new sensor in the "ready-to-drop" position is about 30 seconds. This includes a sensor transport time of 15 seconds. In this respect, a greater number of rows maximize system redundancy. Typically, three (3) rows of T-sensors and two (2) rows of TO-sensors is an ideal combination.

The stages of the measurement cycle are described below.

1) The main cylinder extracts the horizontally stored sensor from the cassette through a specifically designed holding mechanism.
2) After a 90-degree turn, the vertical sensor (head down) is moved to the "ready-to-drop" position.
3) The contact block is lowered into the sensor connector. The sensor is then ready to be dropped.
4) The operator decides when to drop a sensor into the BOF vessel to acquire a measurement.
5) The blast gate opens and the manipulator releases the measuring head into the drop chute.

6) When the measuring head drops into the liquid steel, the signal interpretation by the analysis instrumentation is automatically triggered.
7) Once the reading has stabilized and the measurement is complete, the remaining connection wire and the paper tube are released into the BOF vessel.
8) The manipulator will then place a new sensor into the "ready-to-drop" position.

IV. Field Installation

There was a minimum of fabrication to the existing structure of the upper floor of the BOF to accommodate the ADSS. The walkway was extended in order to place the ADSS near the already existing guide tube. The system was designed with quick disconnects for power, nitrogen, and signalisation cables. This greatly facilitated the installation and allows the ADSS to be removed in case of maintenance.

Instrumentation for signal interpretation and PLC-control unit are situated in the computer room near BOF control pulpit. The automatic manipulator control PLC and signal interpretation instrumentation are inter-connected to each other and to the automation control system of the BOF. The BOF system controls the ADSS drop sequence. This system interface allows the BOF control system to know the state of the ADSS and signal interpretation instrumentation.

V. System Operation

BOF Computer Control

BOF operators initiate the drop probe sequence via the BOF automatic control system. All data from dropped sensors are collected in a database. Items include heat number, drop time, oxygen blow amount, and sensor measurement information. Figure 8 depicts the Probe Drop Panel of the computer controlling system of the BOF. There is a special message screen to alert the operator to the state of the ADSS. All cylinder movements are collected in the ADSS system. Operator or maintenance people can easily trouble-shoot the manipulator utilizing these messages.

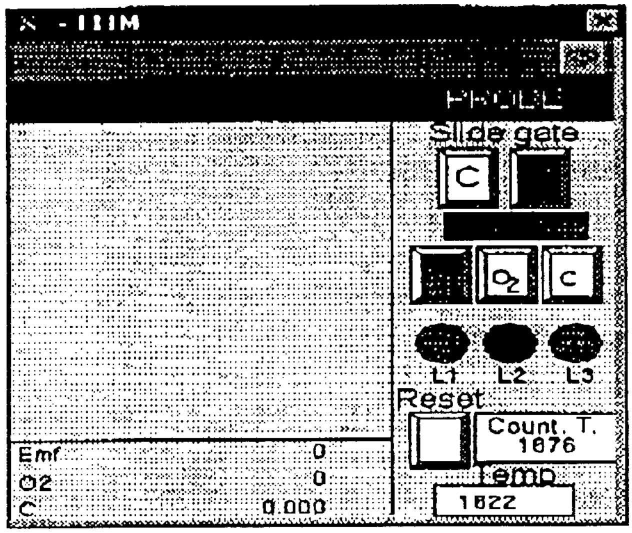

Fig 8: ADSS message screen on probe drop panel of RSW automatic control system

Current BOF Control Scenario Utilizing ADSS

During blow, a T probe was dropped about 40 to 60 seconds before the end of blow. A counter begins to display temperature increase from T probe measurement as a function of time to endpoint of blow. Fast addition hoppers for FeSi and cooling material are available on the BOF. It is possible to add some heat-generating or cooling material at the 15 to 30 second mark to hit the turndown temperature target. Currently, there is no dynamic blow control model. Bath carbon level is predicted by waste gas temperature.

VI. Evaluation of Sensor Performance - Carbon/Oxygen Relationship

A well-defined carbon/oxygen relationship is paramount in the development of a quick tap practice. This correlation is shown in Figure 9, where the TO sensor oxygen measurement end point is compared to the subsequent analyzed carbon at turndown.

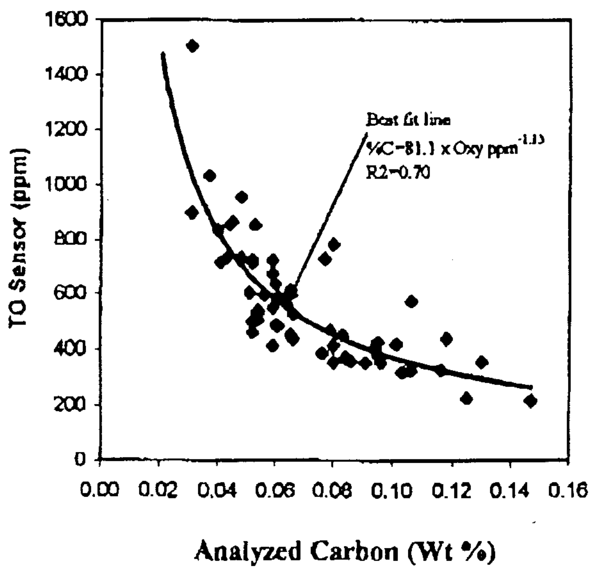

Figure 9: Analyzed Carbon versus Oxygen Relationships. Note good correlation at lower carbon levels.

The graph clearly shows the anticipated correlation. The empirical equation for predicting %C is as follows:

Sensor Carbon Prediction = 81.1 x (Oxy. PPM) $^{-1.13}$

At lower carbon levels (less than 0.08% C), there is a strong correlation of oxygen to carbon, which enables estimating carbon content for direct tapping. The comparison of sensor vs. analyzed carbon is shown graphically in Figure 10.

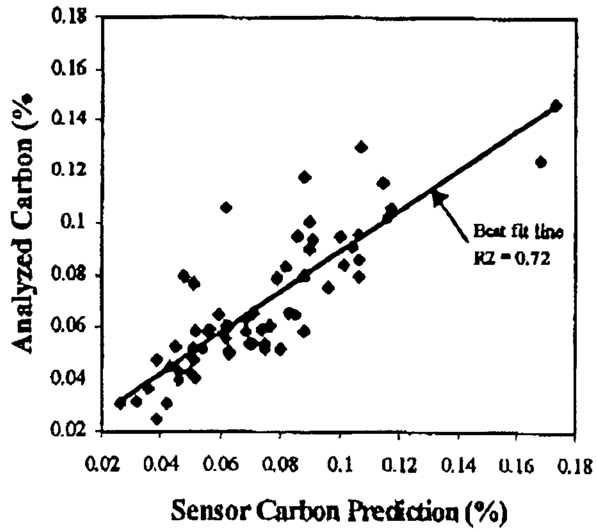

Figure 10: Analyzed vs. Sensor Predicted Carbon

The campaign from which this data was obtained had no bottom inert gas stirring during the evaluation. Earlier results with the bottom stir operational had a higher degree of correlation, carbon to oxygen, as would be expected.

Temperature Pick-Up During Blow

The importance of a during blow temperature measurement is to fine-tune the blow model in order to improve final turndown temperature performance. One way to achieve this control is to define the temperature pick up as a function of the units of oxygen blown, then, construct a table to guide the operators.

The data shown in Figure 11 reveals a very good relationship between the temperature pickup or Δ Temp (delta Temperature) and the elapsed time of blow, or Δ Time (delta blow time).