Theme: Oxygen Steelmaking

TENOVA'S INTELLIGENT *i* BOF® TECHNOLOGY, A MODULAR PACKAGE FOR BOF PROCESS IMPROVEMENT*

Armando Vazquez[1]

Abstract

This paper will provide an overall technology update on Tenova's modular *i* BOF® technology package for improved endpoint detection (Carbon and Temperature), slop detection and auto-tapping control, with a primary focus will be on Tenova's Slop Detection System (SDS). Accurate Slopping prediction is a critical tool in the operation of a BOF. It provides the steelmaker with an additional protective system to increase yield & productivity while reducing operating costs. Tenova Goodfellow's *i* BOF® slop-detection technology uses lance vibration analysis with real-time alerts to give steel makers advance warning of the onset of a slop and a measurement of the slop severity. The system is designed to provide direct feedback control of lance position and oxygen flow rate, for rapid mitigation of potential slopping events. This paper will provide a summary on how the *i* BOF® technology package has been implemented, including trials and general results.

Keywords: BOF; Endpoint; Slop detection; Slop prediction; Lance vibration analysis; Auto tapping.

[1] *Sales & Marketing, Tenova Goodfellow Inc., Mississauga, ON, Canada; goodfellow@tenova.com.*

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

1 INTRODUCTION

Basic Oxygen Furnace **(**BOF**)** is a steel making furnace, in which molten pig iron and steel scrap convert into steel due to oxidizing action of oxygen blown into the melt under a basic slag. The Basic Oxygen Process (Basic Oxygen Furnace) is the most powerful and effective steel making method. About 67% of the crude steel in the world is made in the BOF. The predominant advantages of the BOF are very high production rates and low-residual-element, low-nitrogen liquid steel tapping. The BOF is fed liquid pig iron, almost always from blast furnaces, in amounts ranging from 65 to 90% of the total metallic charge. The average pig iron is approximately 74% of the charge; the balance is recycled scrap.

Figure 1 is a schematic of a BOF. Typical basic oxygen furnace has a vertical vessel lined with refractory lining. Only 8-12% of the furnace volume is filled with the treated molten metal. The bath depth is about 4-6.5 ft (1.2-1.9 m). The ratio between the height and diameter of the furnace is 1.2-1.5. The typical capacity of the Basic Oxygen Furnace is 250-400 t. The vessel consists of three parts: spherical bottom, cylindrical shell and upper cone. The vessel is attached to a supporting ring equipped with trunnions. The supporting ring provides stable position of the vessel during oxygen blowing. The converter is capable to rotate about its horizontal axis on trunnions driven by electric motors. This rotation (tilting) is necessary for charging raw materials, sampling the melt and pouring the steel out of the converter.

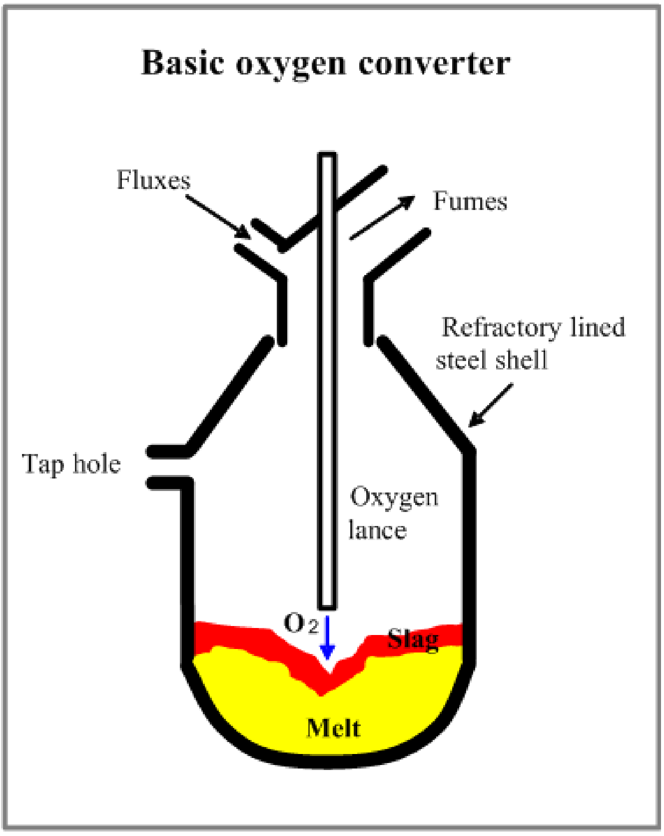


Figure 1. Schematic of a basic oxygen converter.

Tenova Goodfellow Inc. has developed a modular approach for the dynamic control and optimization of the BOF process needs; the *i* BOF® package is based on the real-time measurement of process variables and process data.

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

2 TENOVA GOODFELLOW'S *i* BOF® TECHNOLOGY

i BOF® is a multi-modular technology package designed to improve operating control by providing a process improvements while reducing operation cost.

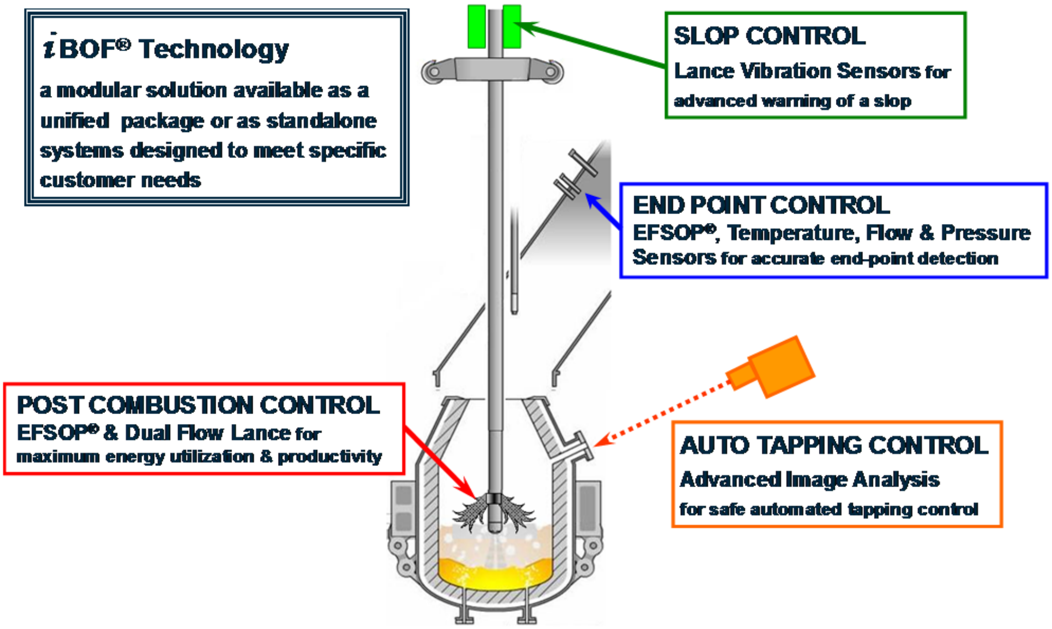


Figure 2. *i* BOF® Technology – multi-modular solution.

As shown on the Figure 2 above, the *i* BOF® package includes the following stand-along solutions.

2.1 Module 1 - End-Point Detection

This module uses a combination of Tenova Goodfellow's EFSOP® off-gas analysis system proven in over 80 steelmaking installations together with proprietary process models and off-gas sensors.

The main objective of the models is to provide an accurate indication, in real-time, of when target temperature and carbon have been achieved. Such an indication would reduce or eliminate the need for re-blows and reduce the reliance on often expensive and maintenance intensive measuring devices. This will ultimately increase yield and productivity while reducing overall operating costs. In addition to endpoint temperature and carbon, real-time slag composition is also generated. This can be used for tighter control of flux additions, thereby reducing refractory wear in the furnace.

ISSN 1982-9345

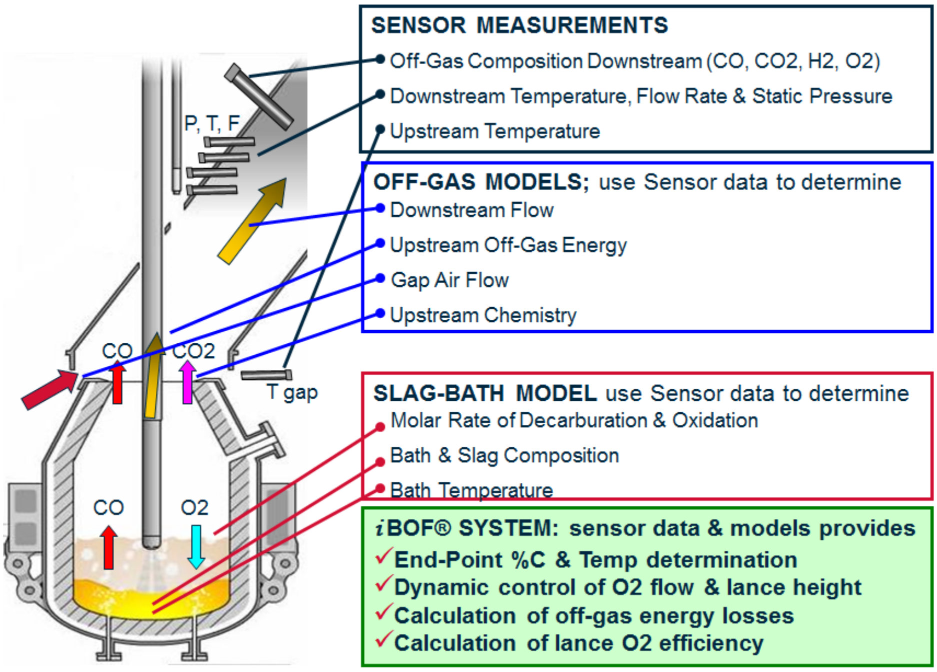


Figure 3. *i*BOF® Module 1 – end point prediction**.**

The Tenova Goodfellow has achieved the following benefits after the implementation of an End Point Solution.

Table 1. Benefits resulting from end point implementation

*i*BOF Technology	Metric	Benefit
End-Point Detection	Addition Carbon	- 2.7%
	Aluminum Deoxidant	- 4.0%
	Oxygen Consumption	- 0.7%
	Ferroalloys	- 1.6%
	Cost Savings – Alloys, Bombs, Refractory & Off-Spec Heats – Yield – Productivity	 ~ $ 1.20 per tls ~ $ 1.75 per tls ~ $ 1.10 per tls

2.2 Module 2 - Early Warning Slop Detection

Uses advanced sensors together with proprietary software to continuously monitor high and low frequency changes in lance vibration. Tenova Goodfellow's proprietary software interprets the signals in real-time to obtain an 20-40 second advance warning of the onset of a slop event as well as an indication of slop severity. The system is designed for dynamic lance height and O_2 flow control to rapidly mitigate the effects of a slop.

---

* *Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

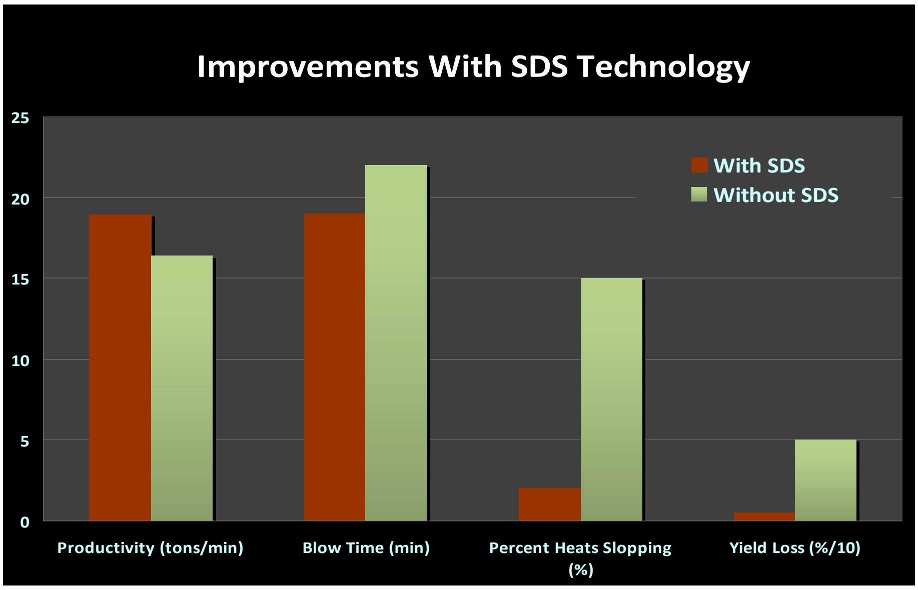


Figure 4. Productivity & yield improvements with slop detection technology.

2.3 Module 3 - Optimized Post Combustion

Enhances “in-BOF” post combustion for increased scrap melting by using a combination of Tenova Goodfellow’s industry proven EFSOP® off-gas analysis system together with dual flow lance technology.

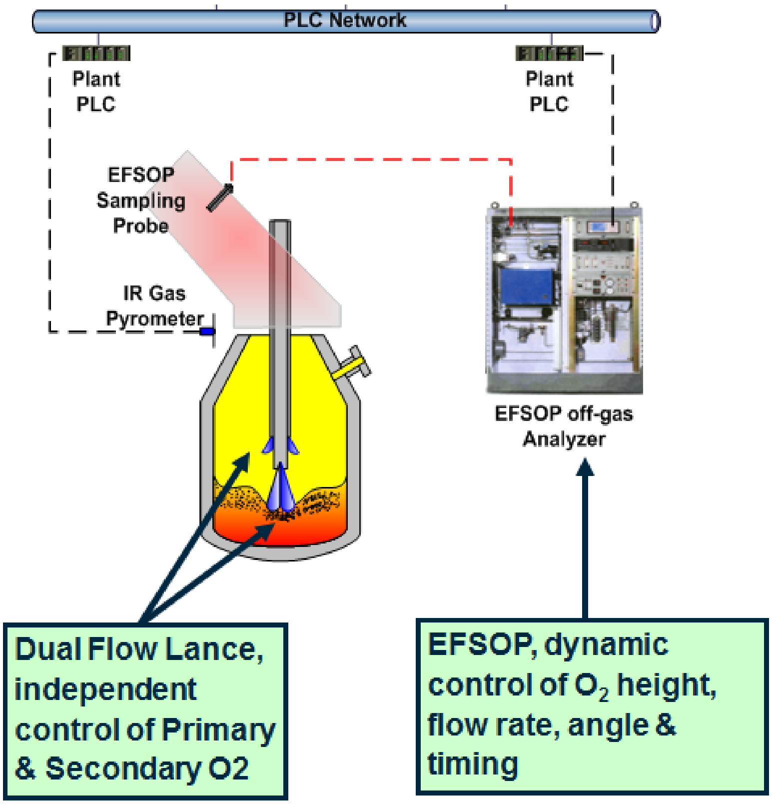


Figure 5. Productivity improvements with post combustion.

---

* *Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

ISSN 1982-9345

Figure 5 identifies the basic configuration for the Post Combustion solution using off-gas information, with anticipated benefits of a Module 3 implementation being:

- ✓ increased scrap usage by ~3-5%, ideal for HM short situations
- ✓ post combustion heat reduces slag viscosity & can be used to mitigate onset of slop,
- ✓ improved end-point temperature control,
- ✓ reduced lance & mouth skull build-up,
- ✓ 5% increase in scrap reduces GHG emissions by ~ 7%,

2.4 Module 4 - Automated Tapping Control

Provides control technology for operator assist or for fully automated tapping control to improve safety, minimize slag carry-over and reduce operating cost.

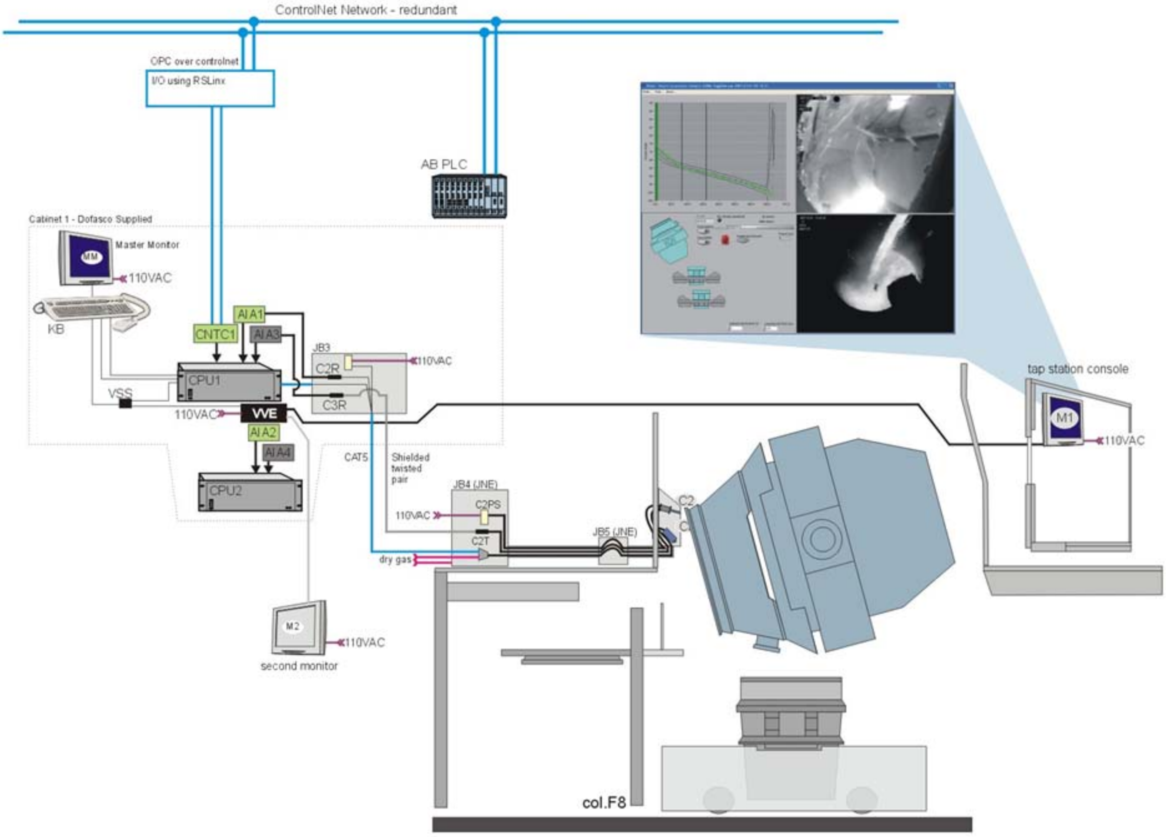


Figure 6. Productivity improvements with automated tapping control.

An implementation of Module 4 will provide the following Benefits:

- ✓ Improvement of Safety Operations
- ✓ Process consistency and improvements on operational logistics
- ✓ Yield Improvements
- ✓ Slag Carryover
- ✓ Productivity
- ✓ Additions Timing

---

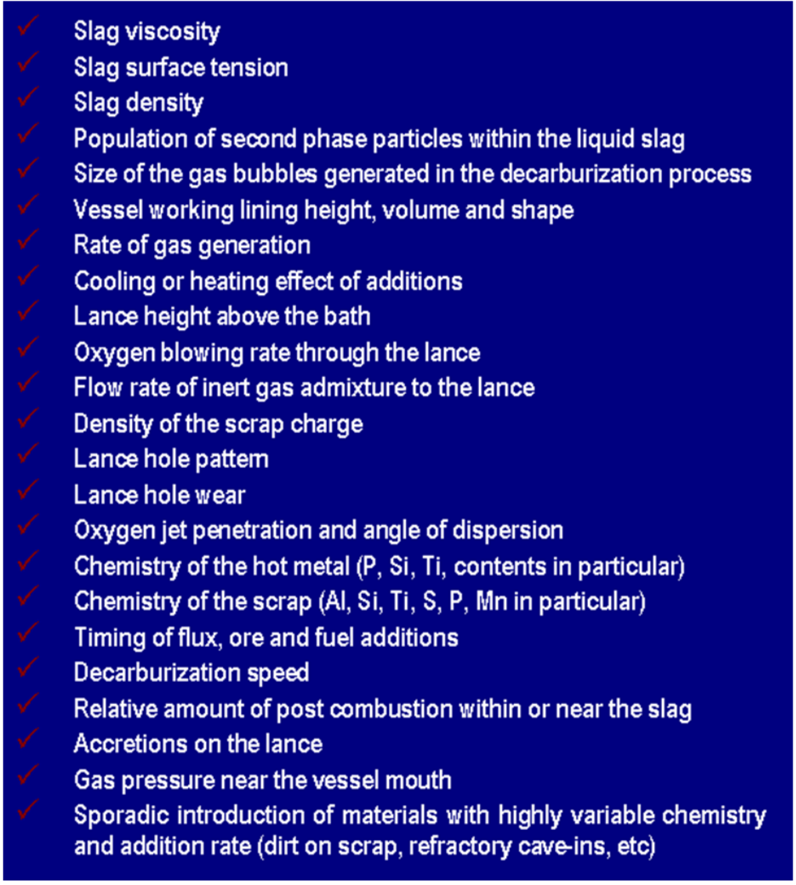
* *Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

3 MODULE 2: SLOPPING ON A BOF

Slopping from a Basic Oxygen Furnace (BOF) vessel is typically unpredictable and problematic event. Losses such as excessive fugitive emissions, yield loss and equipment damaged are a few of may well documented negative results associated with slopping [1]. Major attempts to diminish and prevent slopping have been focused in three main areas:

- Theoretical characterization and modeling of slopping and occurrence probability
- Measurement devices that detect the onset of slopping
- Process changes in real time to diminish the effect of slopping

Slopping is a complex phenomenon dependant on a long list of variables. Those that have been documented include [2,3]:



- ✓ Slag viscosity
- ✓ Slag surface tension
- ✓ Slag density
- ✓ Population of second phase particles within the liquid slag
- ✓ Size of the gas bubbles generated in the decarburization process
- ✓ Vessel working lining height, volume and shape
- ✓ Rate of gas generation
- ✓ Cooling or heating effect of additions
- ✓ Lance height above the bath
- ✓ Oxygen blowing rate through the lance
- ✓ Flow rate of inert gas admixture to the lance
- ✓ Density of the scrap charge
- ✓ Lance hole pattern
- ✓ Lance hole wear
- ✓ Oxygen jet penetration and angle of dispersion
- ✓ Chemistry of the hot metal (P, Si, Ti, contents in particular)
- ✓ Chemistry of the scrap (Al, Si, Ti, S, P, Mn in particular)
- ✓ Timing of flux, ore and fuel additions
- ✓ Decarburization speed
- ✓ Relative amount of post combustion within or near the slag
- ✓ Accretions on the lance
- ✓ Gas pressure near the vessel mouth
- ✓ Sporadic introduction of materials with highly variable chemistry and addition rate (dirt on scrap, refractory cave-ins, etc)

Theoretical characterization and modeling of slopping and occurrence probability has been mainly based on the static charge models founded on the process input parameters. While shown to reduce the occurrence of slopping, the static models fail to account for the dynamic changes of the process. As result, for the heats where high probability of slopping is defined, steel maker is forced to use conservative blow pattern, thus reducing productivity. In addition, static charge models have been found inaccurate as a result of poor accuracy of the input information used for calculation of slopping probability [3]. Overall, static models fail to produce accurate predictions, thus causing unnecessary reduction in oxygen blow rate (and productivity) or fail to predict the event resulting in slopping.

Process changes in real time are used to address the slopping event once detected by the operator via visual observation of slag exiting the vessel mouth. This type of slopping control is used as a reactive measure once the slopping has already began. While the effect of the slopping is significantly diminished by proper process adjustments, numerous negative effects are unavoidable as slopping has already occurred.

Measurement devices that detect the onset of slopping have been proven the most effective proactive measure for mitigation and detection of slopping while maintaining high productivity. Tenova Goodfellow's Slop Detection System (SDS) is real-time measurement device that measures lance vibration to detect the onset of slopping, providing steelmaker's with an advanced dynamic lance control based on the expected severity of slopping. Normal operating conditions produce lance vibrations that are typical for a vessel. These vibrations are associated with oxygen flow rate, cooling water flow, additions and other process parameters. As intensity of lance vibration for predefined frequency range deviates from normal, probability of slopping is increased. Depending on the magnitude of the intensity of lance vibration, advanced measure of severity of onset slopping is calculated and utilized for lance control in a closed loop manor.

Tenova Goodfellow's SDS has been implemented at 5 BOFs in Europe. All 5 systems have been proven effective in advanced indication and prevention of the slopping events. The system's measure of slopping intensity and slopping indications have been used in a dynamic closed loop control of the oxygen lance, mainly via reduction of oxygen flow rate and adjustment of oxygen lance height when slopping is about to occur. Based on the trails performed at these installation sites, high satisfaction of the operations has been observed for both detection of onset of slopping and dynamic lance control. Some of the benefits observed have been increased production, increased yield and reduction in equipment damage caused by slopping.

4 MODULE 2: PROJECT IMPLEMENTATION

The oxygen blowing cycle produces a characteristic lance vibration profile. This blow profile is subjected to significant change during onset of slopping and the slopping event itself. The effect of other disruptions in the blow profile such as lance position, flux addition or blow rate, are readily observed throughout the heat. Since the source and timing of these disturbances are known, they can be easily eliminated from the blow profile. With this in mind lance vibration measurement system was developed along with a means of data archiving of the process parameters needed to fully understand the lance blow profile. The lance vibration and process data were archived for trending and analysis purpose which were used then for development of the onset of slopping detection model.

These lance vibration can be effectively measured using an Integrated Circuit Piezoelectric (ICP) tri-axial accelerometer and monitoring equipment. The ICP-type accelerometer has an amplifier built into the accelerometer body that boosts the piezoelectric crystal voltage to produce high signal to noise ratios over long cable distances. For this reason, the monitoring setup, which includes signal conditioning modules, data acquisition, and a processing unit, can be located remotely to the sensor location, as shown in Figure 7.

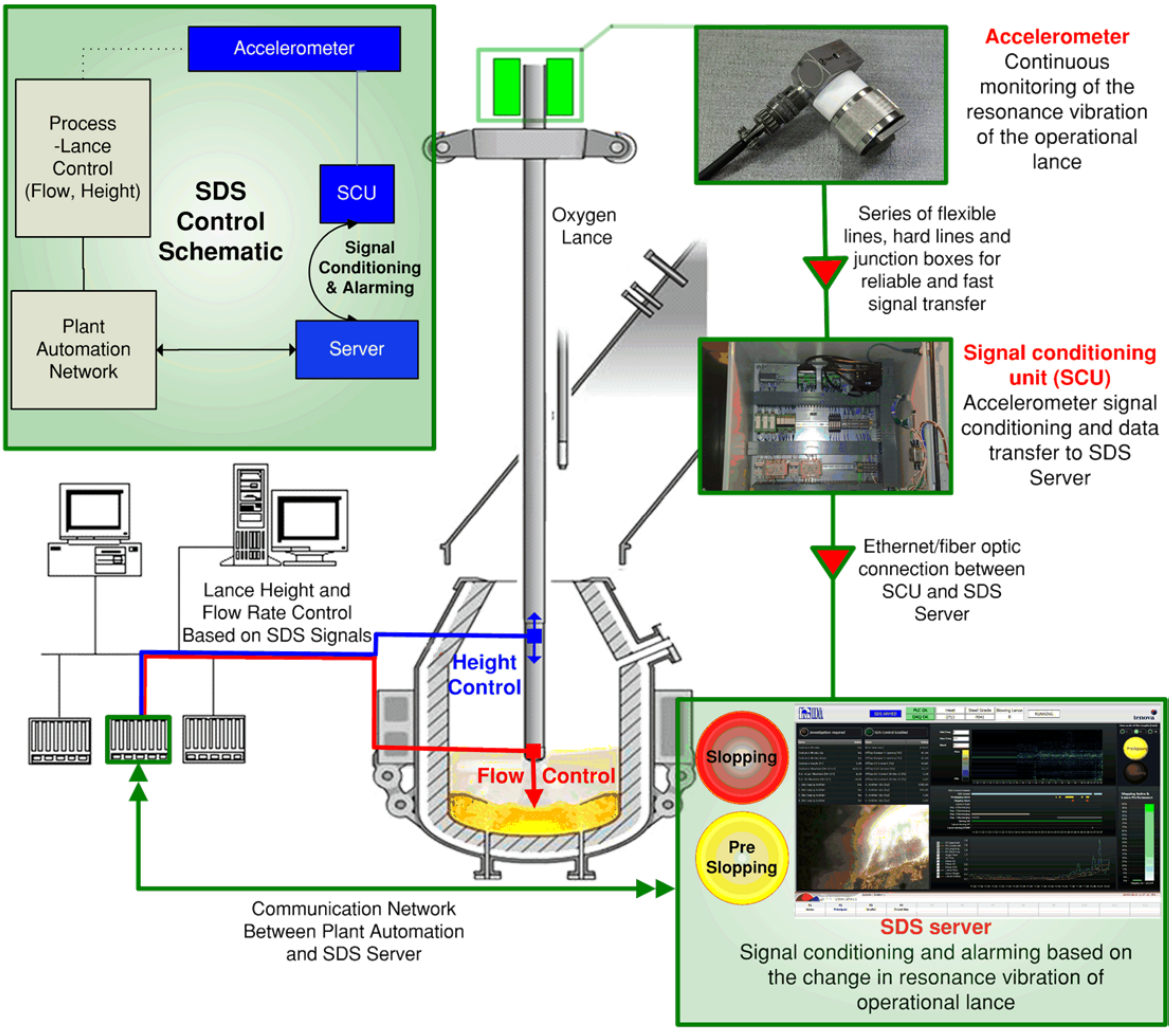


Figure 7. Schematic diagram showing component layout and interconnection.

Communication methods such as FTP, TCP, or OPC using DCOM or other third party software over Ethernet may be used to transfer the various data. The communication method depends upon the data change rate, and how critical the data is to system operation.

Typical plant information that is collected includes:

✓	Heat ID	✓	Bottom blow flow rate
✓	Lance type and identification number	✓	Top blow flow rate
✓	Heats on lance	✓	Top blow pressure
✓	Active lance carriage	✓	Lance height
✓	Lance carriage moving	✓	Off-gas damper position
✓	Flux/alloy addition in progress	✓	Hood position
✓	Blowing on/off	✓	Camera signal
✓	Bottom blowing on/off		

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

The monitoring setup was configured to measure amplitude over a wide range of frequencies. By selecting appropriate frequencies, signals due to slopping within the vessel have been effectively isolated from other process variables.

A camera was installed for confirmation of the slopping event and for tuning of the sensitivity of the system. Proprietary software was developed for analysis of the light intensity to determine the presence and severity of the slopping event. The software produces an analog signal that can be compared against the alarming of the model for additional reassurance of the SDS accuracy and remote tuning of the system. In addition, an image of slopping event is saved which can be then observed for further analysis. A common mounting position of the camera is directly in front or below the vessel as to have a good observation of the slopping event when it occurs.

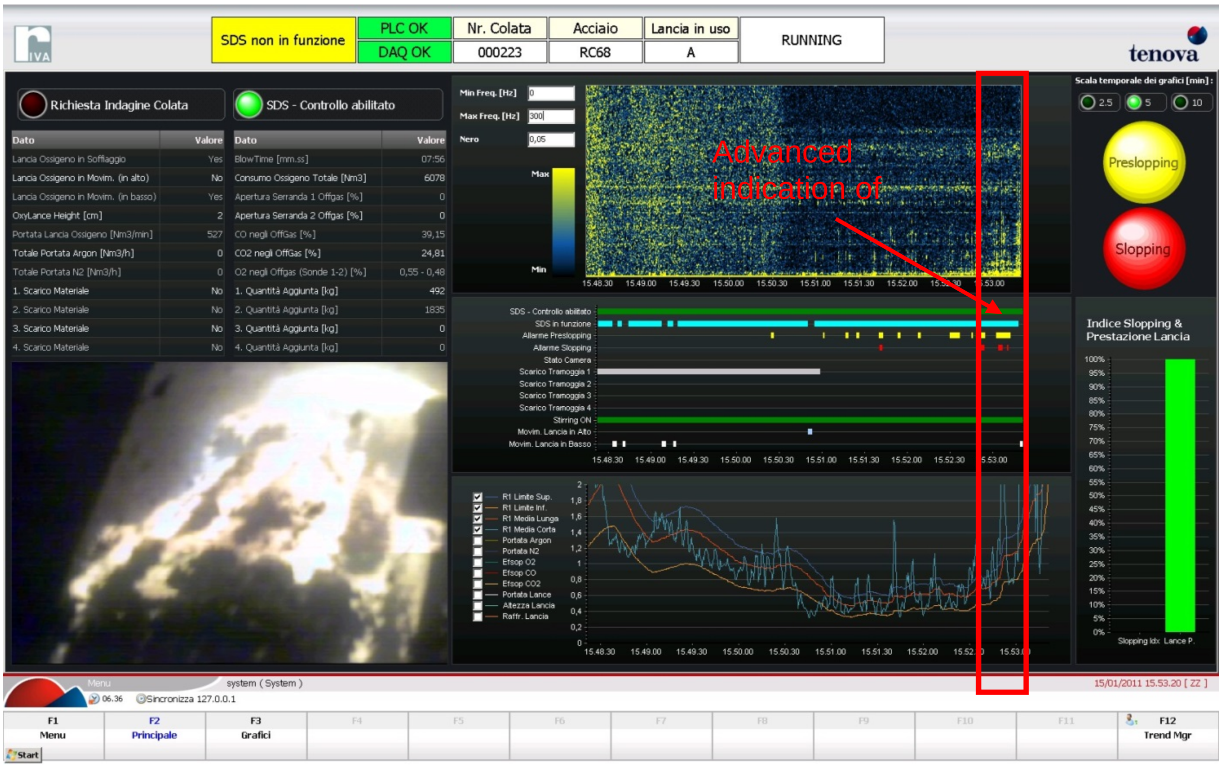
5 MODULE 2: PROCEDURES

Tenova Goodfellow's SDS technology implemented at 5 BOFs in Europe has been proven to provide accurate advanced identification of the slopping event to occur. The system implementation consisted of the hardware installation, slopping range definition, alarm tuning and dynamic lance control configuration. Hardware installation performed on the 5 vessels differed significantly from one vessel to another. The main consideration during the installation was the positioning of the accelerometers on each oxygen lance. Accelerometers were positioned in a strategic location on the oxygen lance carriage in such method to obtain optimal signal to noise ratio of the slopping range.

Range definition was performed through selective elimination of frequency ranges that were associated with the typical process vibrations such as cooling water flow, blowing, and additions. Through the selective elimination final range was defined assuring that it portrayed onset of slopping accurately. Alarm tuning was performed for each vessel as each one exhibited different vibration strength and pattern during slopping, no discrepancy was observed from one lance to the other on individual vessels. Vessel size and design has shown significant variation in vibration profile of the lance, thus the range selection process to be repeated for each of the 5 vessels.

Shown below in Figure 8 is a real-time screen shot of Tenova Goodfellow’s SDS producing alert indications of onset of slopping prior to implementation of the lance closed loop control. Image of a vessel slopping shown in the left corner is a very first overspill of slag over the mouth of the vessel. An indication by the system was produced approximately 45-60s prior to the occurrence of the slopping event. Based on the analysis, if closed loop control of the lance was implemented this slopping event would be diminished.

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*



SDS non in funzione | PLC OK | DAQ OK

Nr. Colata	Acciaio	Lancia in uso
000223	RC68	A

RUNNING

Richiesta Indagine Colata

SDS - Controllo abilitato

Dato	Valore
Lancia Ossigeno in Soffiaggio	Yes
Lancia Ossigeno in Movim. (in alto)	No
Lancia Ossigeno in Movim. (in basso)	Yes
OxyLance Height [cm]	2
Portata Lancia Ossigeno [Nm3/min]	527
Totale Portata Argon [Nm3/h]	0
Totale Portata N2 [Nm3/h]	0
1. Scarico Materiale	No
2. Scarico Materiale	No
3. Scarico Materiale	No
4. Scarico Materiale	No

Dato	Valore
BlowTime [mm.ss]	07:56
Consumo Ossigeno Totale [Nm3]	6078
Apertura Serranda 1 Offgas [%]	0
Apertura Serranda 2 Offgas [%]	0
CO negli OffGas [%]	39,15
CO2 negli OffGas [%]	24,81
O2 negli Offgas (Sonde 1-2) [%]	0,55 - 0,48
1. Quantità Aggiunta [kg]	492
2. Quantità Aggiunta [kg]	1835
3. Quantità Aggiunta [kg]	0
4. Quantità Aggiunta [kg]	0

Min Freq. [Hz] 0
Max Freq. [Hz] 300
Nero 0,05

Scala temporale dei grafici [min] : ○ 2.5 ● 5 ○ 10

Advanced indication of

Figure 8. Slop detection system hmi – early detection of the onset of slopping.

5.1 Dynamic Lance Control

Dynamic lance control was implementing for all 5 vessels in order to automate the corrective actions during the high probability of slopping. Tenova Goodfellow used the steelmaker's proven standard practice of slop avoidance and with the SDS system automated it via implementation of a dynamic lance control based on the SI and alarming indications [4,5].

As shown in Figure 9, lance control adjusted the injection rate of oxygen and avoided the slopping for this heat. During the "Pre-slopping" indication, lance would have been lowered but it could not as it was at minimum height allowed already. Since the risk of slopping was not diminished, the severity was scaled up to "Slopping" intensity. At this point, the rate of injection of oxygen was reduced, automatically. As a result, the corrective measure performed by the SDS dynamic lance control avoided the slopping event.

---

* *Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

TrendMgr 3.5.3.18 is property of TENOVA S.p.A. The company will protect its rights deriving from such property in civil and penal courts according to law

Figure 9. Flow and lance hight adjustment using dynamic lance control.

After the implementation of Tenova Goodfellow's SDS a decrease of more than 90% of the slopping occurrence has been observed. In addition to reduction in slopping occurrences steel maker has also experienced significant increase in productivity. Prior to installation of SDS, this European steel maker was forced to operate at very conservative rate of oxygen injection while refining heats with high probability of slopping. Heats were determined as high slop probability based on their static models. Whit the implementation of the Tenova Goodfellow's SDS, intensity of blowing was only reduced during the period of onset of slopping. These practice allowed for increased oxygen injection rate and overall productivity was increased [4,5].

6 MODULE 2: CONCLUSIONS & RESULTS

The installation and implementation of the Tenova Goodfellow's SDS at the 5 European BOFs was a great success and a great addition to the steel plant's technology. Using the early detection of the onset of slopping dynamic lance control was implemented. The implementation of the dynamic lance control has shown improvement in the production rate by effectively reducing down time caused by slopping. The period of heat where conservative injection of oxygen was necessary to avoid slopping was also reduced. Finally, increased yield and reduction of equipment damage were also observed benefits of the implementation of the Tenova Goodfellow's Slop Detection System.

The system performance was evaluated by the European Steelmaker and officially determined to have 99% early detection rate, with low rate of false alarms. Outside of successful slop evasion (~90%), the steelmaker has exhibited significant improvements in other aspects of production, including safety, productivity and equipment life as shown in Figure 10.

** Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*

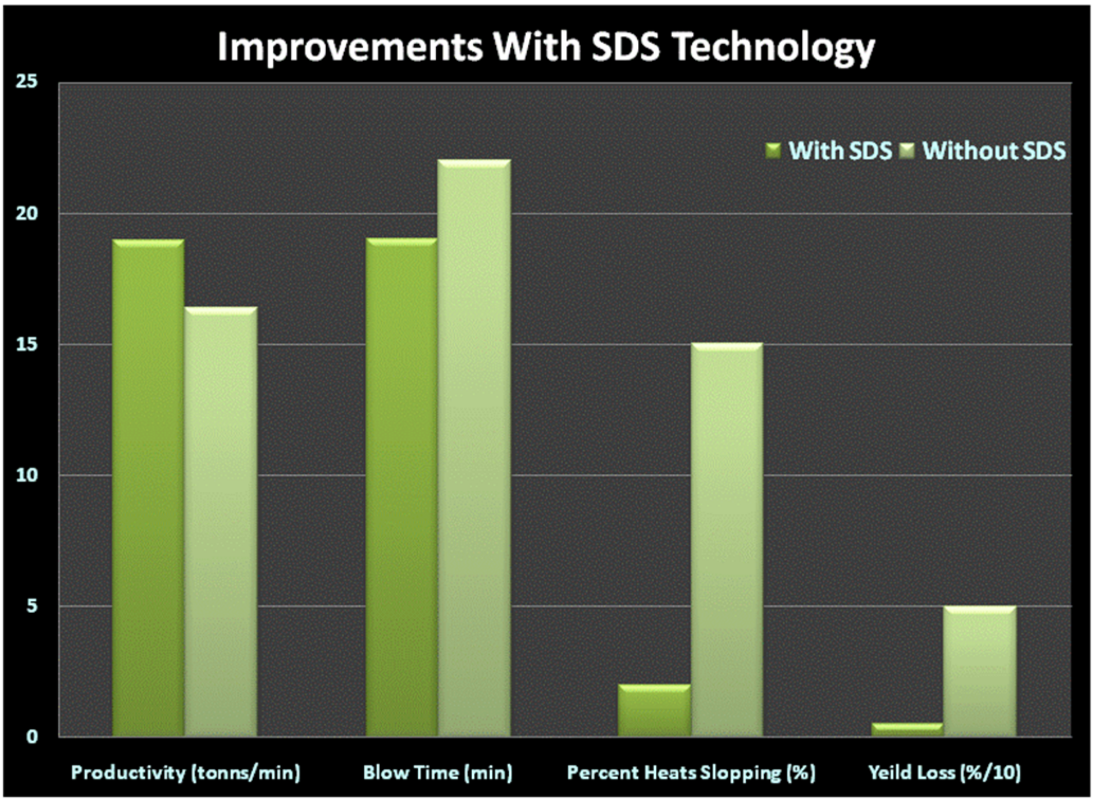


Figure 10. Benefits calculated by Tenova Goodfellow's Slop Detection System.

REFERENCES

1 Shakirov M, Boutchenkov A, Galperine G, Schrader B. Prediction and Prevention of Slopping. ISSTech 2003 Conference Proceedings, p. 655-666, 2003.
2 Evestedt M, Medvedev A. Model-Based Slopping Detection in a Top-Blown Steel Converter, Department of Informational Technology, Uppsala University, Sweden, 2007.
3 Doe J. Prediction and control of slag slopping in BOF using microwave gauge. Trans. ISIJ. 1984;24:502.
4 Davis O, Scipolo V, Vazquez A. Mathematical modeling of the BOF for end point prediction using EFSOP® technology. ABM, Brazil 2010
5 Scipolo V, Todorovic I, Vazquez A. Improved BOF performance and safety through effective mitigation of slopping events. 18th Steelmaking Conference, EXPO IAS 2011, Rosario, Santa Fe, Argentina, 1-3 November 2011.

---

* *Technical contribution to the 45th Steelmaking Seminar, May 25th-28th, 2014, Porto Alegre, RS, Brazil.*