SLOPPING DETECTION SYSTEM AS A TOOL TO IMPROVE BOF PERFORMANCE AND SAFETY[1]

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Abstract
Accurate slopping prediction is a critical tool in the operation of a BOF. Tenova Goodfellow's Slop Detection System (SDS) provides the steelmaker with a protective system to increase yield & productivity while reducing operating costs. Traditionally, operators rely on static modeling and operator experience to predict slopping occurrences. These options however, have a limited ability to predict slopping as they do not account for process dynamics and are adversely affected by uncertainties in the initial conditions. Tenova Goodfellow's Slop Detection System uses lance vibration analysis with real-time alerts to give steel makers advance warning of the onset of slopping and a measurement of the onset slopping severity. The system provides direct feedback control of lance position and oxygen flow rate, for rapid mitigation of the effects of a slopping event. This paper will provide a summary on how the Tenova Goodfellow's Slop Detection System was implemented at 5 BOFs in Europe, including trials and results. The advanced slopping detection system successfully provided the steelmaker with the opportunity to increase productivity while lowering the risk of delays caused by slopping occurrences.
Keywords: BOF; Slopping; Lance vibration analysis; Slop prediction; Dynamic lance control.

SISTEMA DE DETECÇÃO DE PROJEÇÃO COMO FERRAMENTA PARA MELHORAR O DESEMPENHO E A SEGURANÇA DO BOF

Resumo
A previsão precisa de projeção é uma ferramenta crítica na operação de um BOF. O Sistema de Detecção de Projeção (*SDS - Slope Detection System*) da Tenova Goodfellow oferece ao aciarista um sistema preventivo para aumentar o rendimento e a produtividade e reduzir os custos de operação. Tradicionalmente os operadores confiam em modelos estatísticos e experiência operacional para prever a ocorrência de projeções. Essas opções, entretanto, possuem uma capacidade limitada para prever projeções pois não contam com a dinâmica do processo e são afetadas negativamente por incertezas nas condições iniciais. O Sistema de Detecção de Projeção da Tenova Goodfellow utiliza a análise de vibrações da lança com alertas em tempo real para fornecer ao operador avisos antecipados do início da projeção e uma medição da intensidade da projeção incipiente. O sistema fornece um retorno direto ao controle da posição da lança e da vazão de oxigênio, para mitigar rapidamente os efeitos de uma ocorrência de projeção. Este trabalho apresenta um resumo de como o Sistema de Detecção de Projeção da Tenova Goodfellow foi implantado em 5 BOFs na Europa, incluindo testes e resultados. O sistema avançado de detecção de projeção ofereceu ao aciarista a oportunidade de aumentar a produtividade simultaneamente à redução do risco de atrasos causados pela ocorrência de projeções.
Palavras-chave: BOF; Projeção; Modelos de carga estática; Análise de vibração de lança; Previsão de projeção; Controle lança dinâmica.

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1 INTRODUCTION

Slopping from a 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 known negative results associated with slopping. Major attempts to diminish slopping have been focused in three areas:

- theoretical characterization and modeling of slopping and occurrence probability;
- measurement devices that detect the onset of slopping; e
- process changes in real time to address the onset of slopping.

Slopping is a complex phenomena dependant on a long list of variables. Those that have been documented include:

- 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, WOBs).

Theoretical characterization and modeling of slopping and occurrence probability has been mainly based on the static charge models founded on the initial process parameters. While effective in reducing probability of slopping, the static models fail to correct for the dynamic changes of the process forcing steel makers to follow conservative blow pattern for the entire heat causing reduction in productivity.

Process changes in real time to address the onset of slopping have been used as a reactive measure once the slopping has been detected. 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 for mitigation of slopping while maintaining high productivity. Tenova Goodfellow's Slop Detection System 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 Slop Detection System 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 measures of slopping intensity and indications have been used in a dynamic closed loop control of lance, mainly via reduction of oxygen flow rate and lance height. 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.

2 MATERIALS AND METHODS

As an alternative to the conventional technologies that have been applied to mitigate the effects of slopping, a vibration based system has been developed by Tenova Goodfellow. The harsh operating conditions inside the vessel make measurement difficult, thus creating a need for external detection of onset of slopping. It was decided that a better approach might be to monitor the vibration of the lance and attempt to correlate this to slopping conditions.

The oxygen blowing cycle produces a characteristic lance vibration profile, which is disrupted during slopping events. The effect of mitigating measures, such as lance position, flux addition or blow rate, is readily observed in the vibration profile. A measurement system was developed along with a means of data archiving. The vibration and process data were archived for trending and process improvement that lead to significant identification and reduction in slopping events.

Once slopping is detected, operations may take remedial action to reduce slopping, possibly including:

1. Adjustment of lance height
2. Adjustment of oxygen flow rate
3. Flux addition to adjust viscosity
4. Lime addition
5. Post combustion of CO in the vessel

The BOF lance is subject to forces that cause it to move and vibrate at various frequencies. Vibration may be due to the force of the lance tip oxygen jet, lance carriage movement, water flow in the lance, gas evolution from chemical reactions, and material movements within the vessel. This 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 1

Figure 1below.

A convenient and safe place to mount the sensor was decided to be on the lance carriage, away from the harsh environment near the vessel mouth. In all of the current installations this location has been proven to minimize the effect of surrounding vibrations yet effectively measure the vibrations of the lance during blowing.

The vibrations can also be influenced by other process variables, so an appropriate method of communication needs to be established between the slopping detection system and the plant PLC, Level 1.5 or Level 2. This enables the sensing system to make signal compensation adjustments based upon process events.

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

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 is used for confirmation of the slopping event and for tuning of the sensitivity of the system. Software has been 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 Slop Detection Systems accuracy. In addition for every slopping event an image 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 as shown in

Figure 1.

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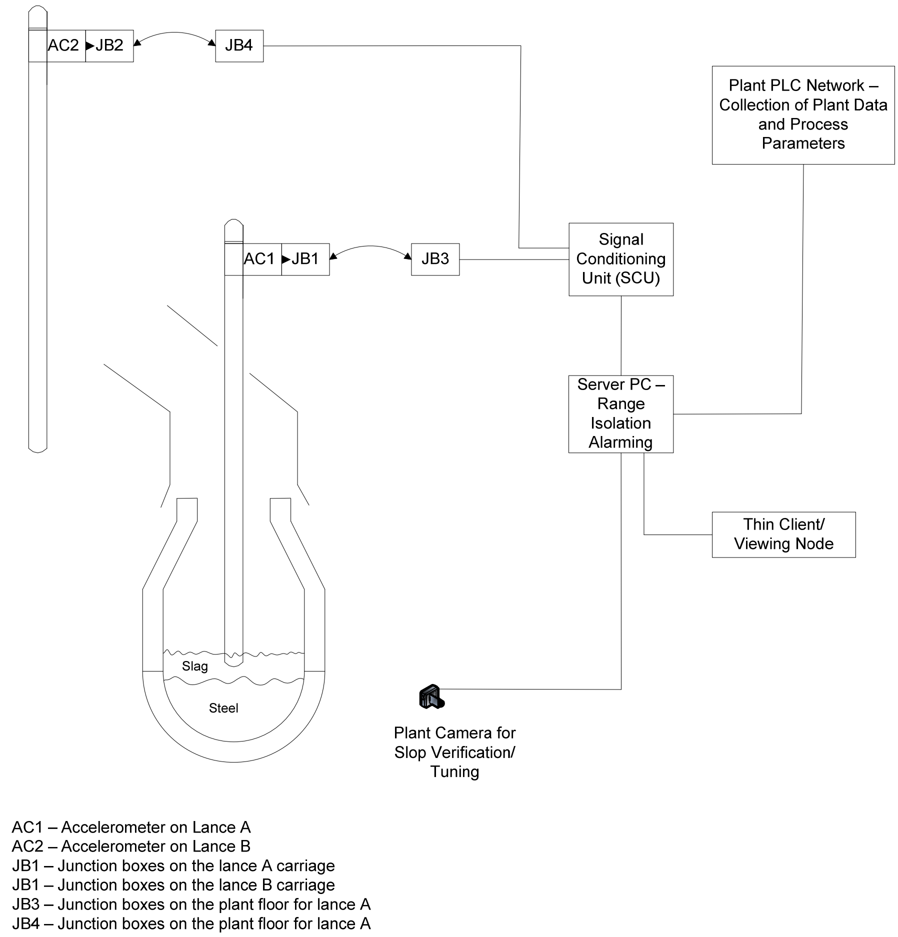

Figure 1: Schematic diagram showing component layout and interconnection.

3 RESULTS AND DISCUSSION

Tenova Goodfellow's Slop Detection Systems implemented at 5 BOFs in Europe have been proven to provide accurate advanced identification of the slopping event to occur. The system implementation consisted of the hardware installation, range definition and alarming tuning. All 5 system hardware installations were similar, where in all the location of the accelerometer was on the lance carriage. Range definition was performed through selective elimination of frequency ranges that were associated with the typical process vibrations (i.e. cooling water, blowing, and additions). Trough the selective elimination final range was defined assuring that it portrayed onset of slopping accurately. Vessel size and design has shown significant variation in the pattern of the lance vibration, forcing the range selection process to be repeated for each of the 5 vessels.

3.1 Range Definition

Raw vibration signal coming from the accelerometer contains wide range of frequencies where only a small set is useful for detection of initiation of slopping. As a result the first step in detection of the onset of slopping was definition of the frequency range at which the slopping event was most observable. The process vibrations were noted to vary significantly from one converter to another based on the vessel design, lance design, carriage design and general plant surrounding (i.e. location of the pumps, water cooling channels, and electrical lines routing).

Range defining was performed on site trough intense observation of the process and slopping events. Elimination of all the ranges caused by variables other then slopping (Cooling water, lance blowing, additions…) has been performed. In the end a particular range that accurately represented vibrations caused by onset of slopping was obtained as shown in Figure 2 below. During the installation of the Slop Detection System on the 5 BOF vessels different ranges were defined for each vessel. However the vessels located on the same site have shown more similarities in the range defining process then when the vessels of 2 different sites were compared.

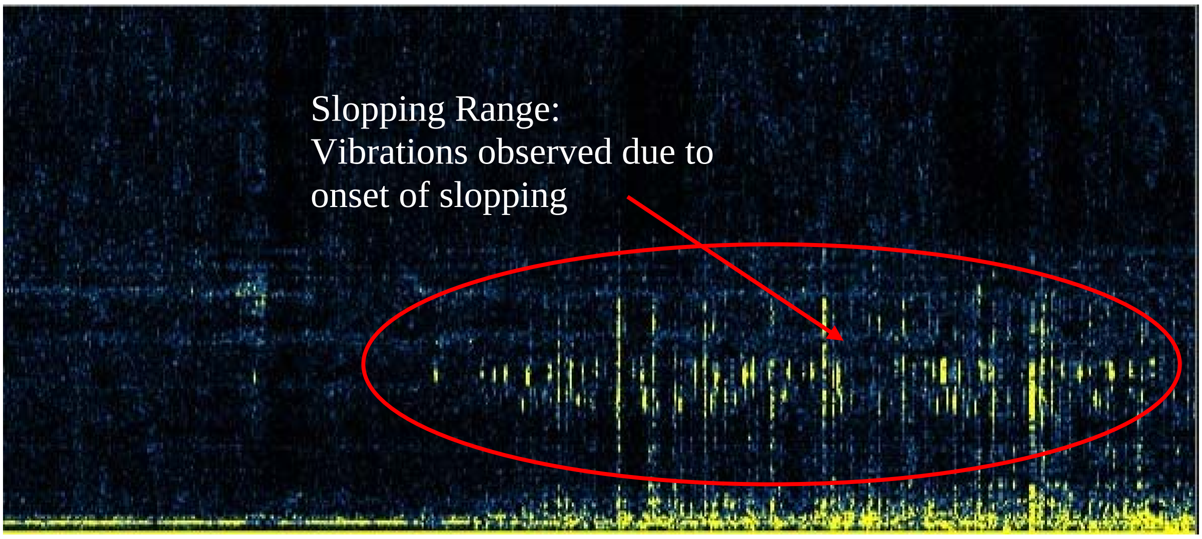

Figure 2: Typical vibration observed during the onset of slopping.

During the intense onsite observation, when deviation from normal vibration was observed in the previously defined slopping range, a slopping event would follow in the near future (usually 30 - 40 seconds after). Based on these observations, a tunable alarming model was defined.

3.2 Alarm Sensitivity Tuning

The vibrations for the defined range was analyzed to determine the normal operating vibrations and then compared with the operation where onset of slopping was present. A measure of the deviation of vibration from normal at the defined frequency range was used to indicate the severity of the onset slopping event. The measure was defined as Slopping Index (SI) and it had direct correlation to the magnitude of the onset slopping.

The system was designed to produce two separate alarms based on the severity of the slopping event. The alarming conditions were based on the slopping index, a calculation performed by internal model. The sensitivity tuning was performed based on the client recommendations and Tenova Goodfellow's experience.

A typical slopping index observed in a single heat is shown in Figure 3 below. The magnitude of the slopping index was proportional to the rate of the slag rising and it was used to alert operations of the onset of the slopping and eventually for the implementation of the dynamic lance control. Figure 3 is showing slopping index for

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the length of the entire heat. The beginning and the end of heat have minimal risk of slopping manifested by low slopping index. During the middle of the heat significant increase in slopping index was observed. This situation was a result of change in the lance vibrations caused by rapid raise of slag in the vessel. In this particular case slopping was mitigated by reduction of oxygen flow rate and lowering of the lance.
Thresholds of the slopping index have been defined based on the onsite analysis of the severity of slopping and slopping index. The thresholds are used to trigger indications for the operations to indicate what corrective measure should be performed. Two separate thresholds have been generated, where lower threshold indicates "Pre-Slopping" (yellow indicator in
Figure 4) conditions, which result in slight modification of the operation of the vessel. The second indication, "Slopping" indicates large probability that slopping will occur and requires extensive adjustment of the process to avoid the slopping event (red indicator in
Figure 4). Initial trails were conducted on manual adjustment of the lance flow and height. Once the tuning and accuracy of onset slopping detection was established a closed loop control of the lance was implemented. The closed loop control showed better slopping mitigation due to faster response compared to manual process adjustment performed in the initial stages.

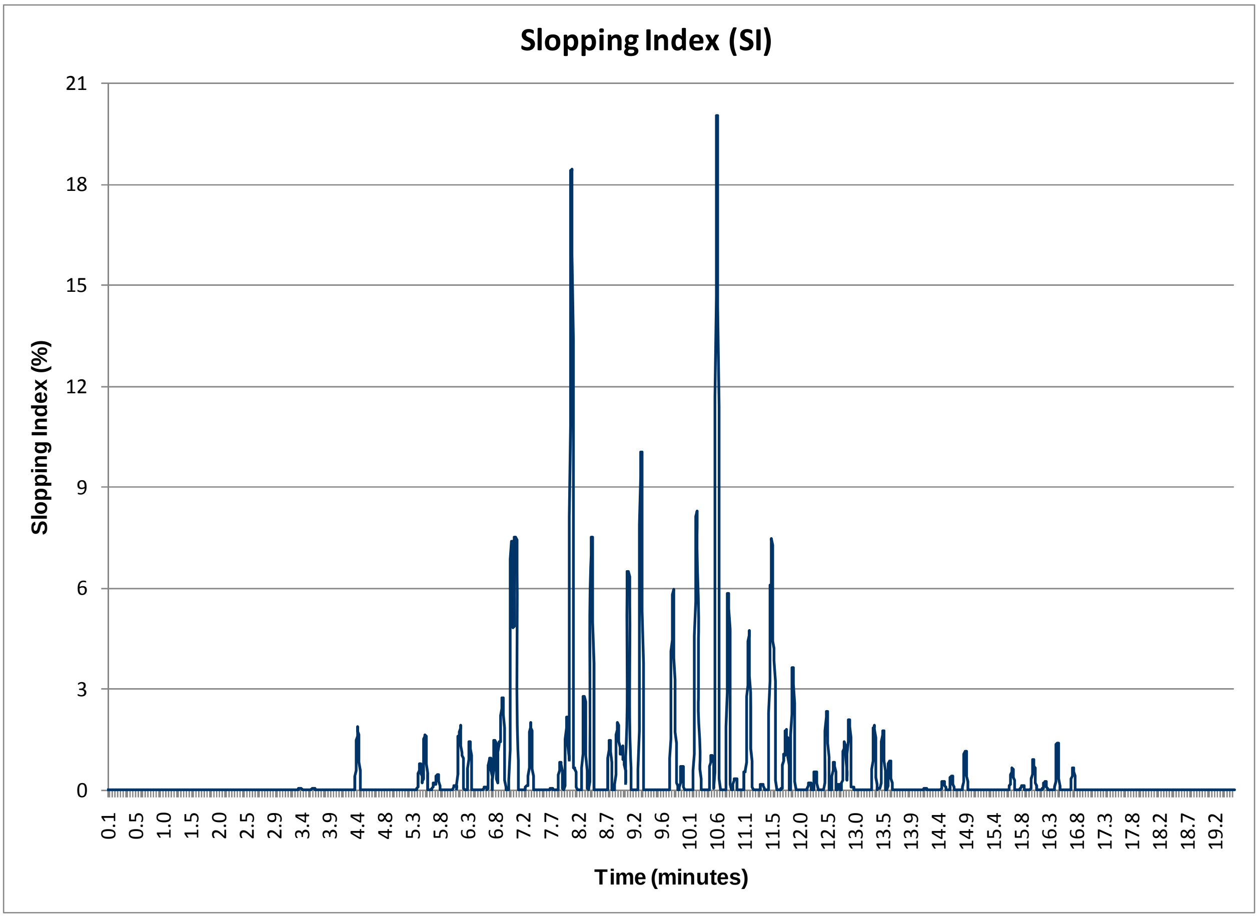

Figure 3: Indication of the slopping index for a heat with high probability of slopping.

As a result quick mitigation of slopping was possible due to the early warning produced by Tenova Goodfellow's Slop Detection System. Using both, slopping index and the threshold indicators for the pre-slopping and slopping conditions, slopping events were mitigated through dynamic lance control.

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Shown below in Figure 4 is a real-time screen shot of Tenova Goodfellow's Slop Detection System 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.

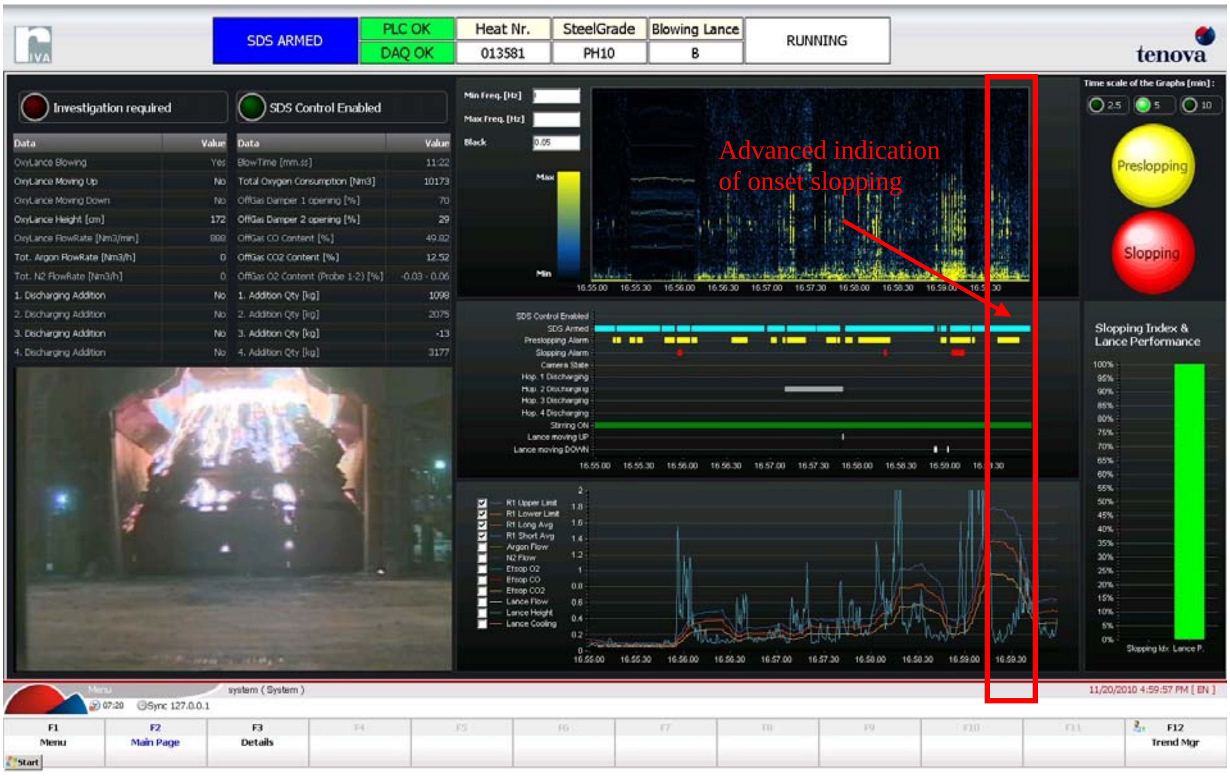

Figure 4: Slop Detection System HMI – Early detection of the onset of slopping.

Following the training of the operations on the system indications and implementation of the lance closed loop control slopping events such as the one shown above were completely avoided. The systems ability to produce an accurate advanced warning of a slopping event and implementation of dynamic lance control proved to be valuable tool for increase in production and safety at these 5 European installations.

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 Slop Detection System, 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 CONCLUSIONS

The installation and implementation of the Tenova Goodfellow's Slop Detection System 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.

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