Automated mold flux feeders for Industry 4.0 application

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New sensor technologies have been applied to the mold flux feeder, automating the feeding processes and enabling data collection of process information previously unavailable. Analysis of the information to determine operational, maintenance and quality relationships critical to sustainability and operational efficiency is now possible. The current automation and technology of the Imerys feeding systems, and examples of observations from the mold flux feeder of mold level variability and bias flow will be presented. The objectives using edge computing, ERP systems, augmented reality and cloud analytics of previously isolated data will be discussed with the outcome of integration with operational, maintenance and inventory management solutions.

KEYWORDSS: MOLD FLUX FEEDERS, SENSORS, AUTOMATION, MOLD FLUX, CONTINUOUS CASTING;

INTRODUCTION: MOLD FLUX FEEDERS

Applying mold flux with feeding equipment has been a standard practice since the introduction of granular mold flux for continuous casting of steel. Imerys equipment designed specifically for mold flux application followed during the late 1990's [1] as the conversion from powder to granular mold flux occurred. The equipment provides even, constant flux addition, replacing a manual addition practice where the operator would add the flux as a batch application. The negative impact of the batch addition practice has been measured and well documented over the years for the effect on mold level and meniscus stability [2], and ultimately quality and operational performance. Despite the improvement over the manual additions practice, the early feeding equipment still had limitations and lacked the ability to measure, control and collect information from the process.

The advancement of flux feeding automation has been developed with the addition of sensors to automate the flux feeding and enable collection of process information.

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1. Load cells for consumption monitoring
The information from load cells allows consumption to be monitored and collected. Programs for independent mold feeding by application rate are now possible for billet and bloom casters. Alarms for feeding issues and machine empty status can be observed.

2. Lasers for feeding control
Lasers for slab casting allow measuring of the flux thickness with calibration to the mold level system. The rate of flux application is controlled to maintain a steady flux thickness.

3. Thermal flux thickness control
The temperature of the flux surface provides an indication of the flux thickness from the insulation of the layer thickness.

4. Silos with automatic flux selection
Silos with valving and level measurement allow automatic flux changes from the HMI and/or customer signal. Silos refilling is also indicated.

5. Robotic arm for distribution

A programmable linear actuator moves the flux feeding outlet across the mold surface for optimal flux distribution at all points in the mold. Control of the speed and width of coverage are realized.

The control automation and data acquisition bring additional benefits to the feeding process at the mold. Maintaining a stable, even flux layer on the steel provides constant thermal insulation at the meniscus and removes the unknown variability of an operator controlled flux layer practice. Feeding under controlled conditions displays information that can be critical to the quality and operational stability of the process regarding mold level and bias flow. Moving forward, it is not enough to simply control and collect, but to take advantage of the information with predictive modelling and monitoring. As the evolution of the feeding equipment continues into 4.0 integration, the next step is to use the information for self diagnostics, monitoring and analysis.

EXAMPLE OF LASER MOLD LEVEL MONITORING

Mold level control has a major impact on the steel quality, and much work has been done to improve the stability and is well documented [3]. There is a heavy reliance on the level control system, to be precise in response to the uncertainties and disturbances of the casting process. The necessity for tuning and filtering of the mold level sensor for process control can lose sight of what is actually occurring in the mold, and consequently can give a false impression of stability.

For slab casters, the mold flux feeder uses lasers to measure the distance to the top surface of the flux. The sensor positions are calibrated to the mold level as a reference point through the feeder PLC program to read in mm (or inches) of flux thickness. The outcome is a controlled feeding to keep the flux thickness constant at the desired thickness.

The use of high precision lasers also provides additional information based on the absolute distance change seen at the surface of the flux layer, and gives a second view of the mold fluctuations and actual level control. During application, variations can be observed that may go unnoticed with the caster steel mold level system and collected data in the caster system. Laser mold level monitoring is based on the principles below:

- The lasers measure independent of each other, on each side of the mold
- Using the unfiltered signal for quick response, fluctuations occur together in magnitude and frequency indicating true mold level variability

The following figures demonstrate the measurements:

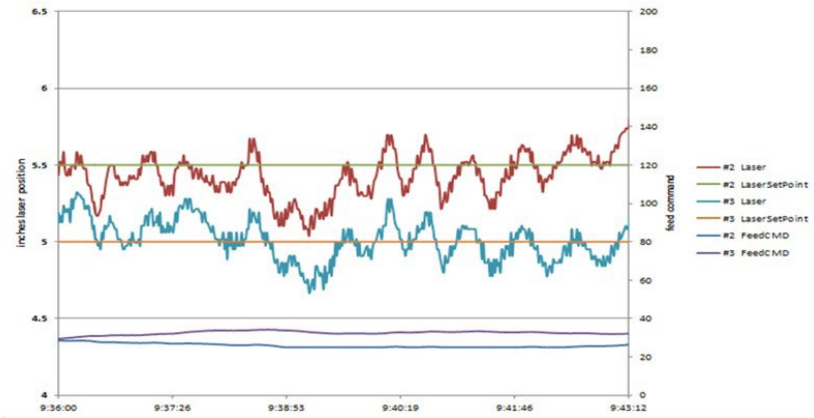

Fig.1 - The lasers (red and light blue) and feeding signals (purple and dark blue) are displayed on the chart. The setpoint distance for each laser (orange and green) are followed for control of the mold flux thickness. The trend is monitored over ½ hr, using a laser scale of +/- 1.25 inches. The agreement of the magnitude and behavior of the laser signals demonstrates the presence of mold level fluctuations.

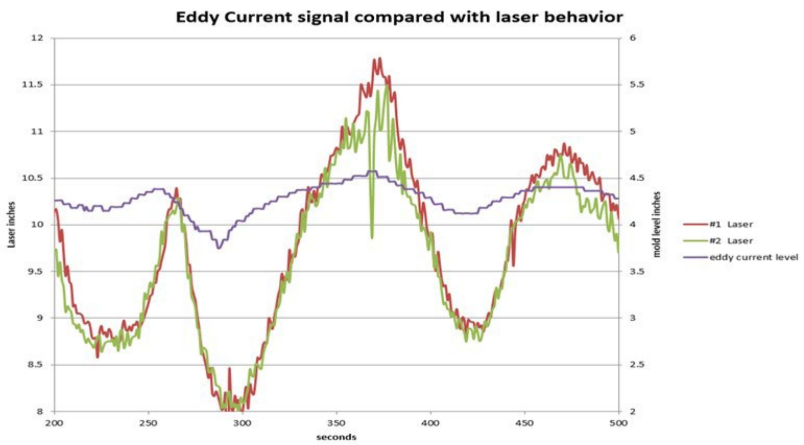

Fig.2 - During an unstable mold event capture for 300 seconds, the lasers (red and green) were recording the actual mold level variation. The customer mold level signal (purple) is on the same scaling and followed the same trend, but with a filtered response not representing the true mold level fluctuations.

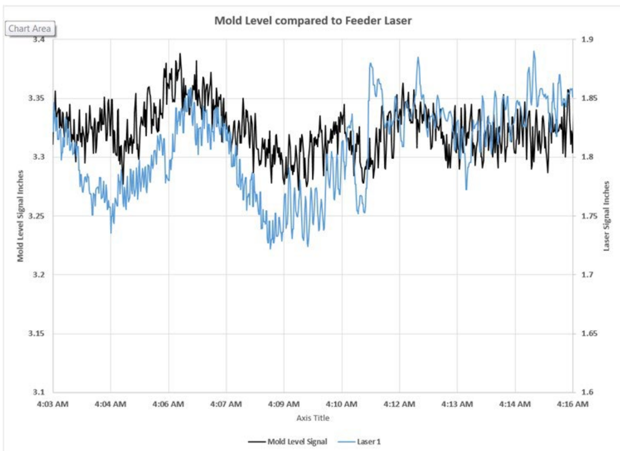

Fig.3 - The graph shows good agreement in signal behavior and amplitude fluctuation. between the laser signal (blue) and the mold level (black) on the same scale range, giving confidence to the mold level control performance.

EXAMPLE OF BIAS FLOW MONITORING

Bias flow can be detrimental to steel quality in the continuous casting mold [4]. The additional flow to one side of the mold results in excessive turbulence causing mold level fluctuations, flux entrapment and can also inhibit the steel shell formation. Determination of bias flow is difficult and often not apparent as it occurs below the mold flux layer. With the automatic feeding of the mold flux using the lasers and load cells, the feeding rates can measure the bias effects at the steady state flux thickness. A phenomenon is observed when bias flow is present that the feeding of mold flux becomes unbalanced to maintain a constant flux thickness. This is indicative of an uneven thermal profile to melt the flux into slag. Figure 3 displays a bias flow event captured prior to a tube change.

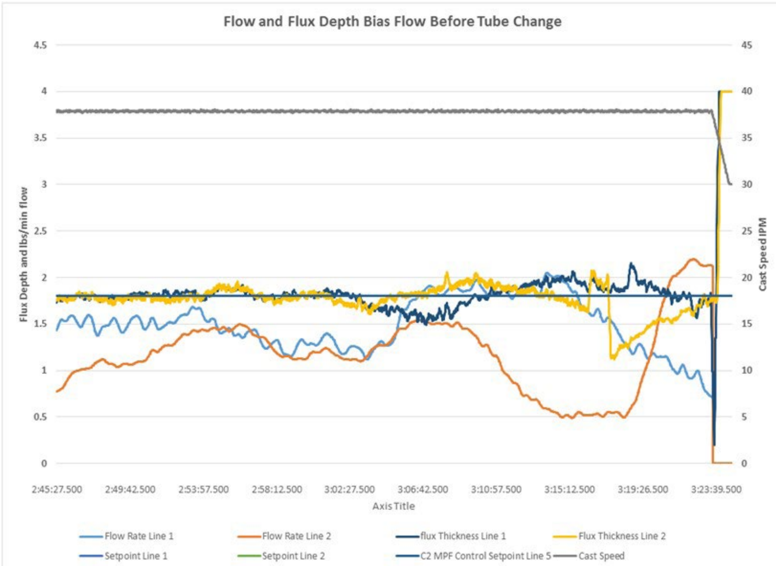

Fig.4 - At steady state speed (grey) and flux thickness (yellow and dark blue), a bias flow condition occurs prior to a tube change. During the bias flow event, a 4:1 difference of mold flux consumption was measured.

Bias flow is a phenomenon that can be noticed with the automated feeding of the flux feeder. This information properly analyzed can potentially assist with understanding the flow relationship with cast speed and width, the presence of plugging, and help evaluate tube design changes in operation.

DATA ANALYTICS

The examples of mold level and bias flow monitoring are just 2 observations from the sensor information presented by the mold flux feeder. There are likely more key observations that can be made through evaluating the information and finding correlations. The traditional use of data is to gather information and store it in a database for analysis after an event. Modeling of the casting process is also a tool used [5], but measured information identifies actual events in real time that have an impact on quality and productivity.

Future objectives are applying decision making and process steering occurring in real time. This will first require identification of correlations from the data. To assist with the collection and combination of data from the devices and process on a centralized platform, edge computing devices now exist. In addition, to provide the initial analysis, cloud database platforms can be accessed to perform remote evaluation of the edge data, to enable continuous improvement.

The outcome from the data analysis will bring benefits by continuously developing software to assist in the following ways:

- Comparing signals to verify optimal operation of devices
- Determining events linked to quality and operational stability
- Evaluating mold flux performance parameters and optimization
- Evaluating caster equipment (ex. new tube design, mold level control adjustments)
- Feeder maintenance and performance management
- Automated reports of events and overview of productivity
- Inventory management with ERP connectivity to customer and vendor

MAINTENANCE OBJECTIVES

The flux feeder is designed for low maintenance, but occasionally it is necessary to troubleshoot an issue. Having a workforce close to the customer is a benefit for reaction time, but does not always bring the necessary knowledge and experience required. Augmented reality technology to connect with an equipment expert located remotely is now available to bring an expert onsite. Smart glasses allow a specialist to work together with an onsite resource. Wearing a set of glasses and microphone on a hard hat, the local resource can make a connection through a mobile phone. The expert connects via laptop virtually coming onsite to see what the local resource sees. The onsite resource has a field of vision that is also collaborative, allowing the expert to freeze views, annotate areas, share their computer screen onto the glass lenses, and translate language in real time. This tool is currently being brought into the Imerys organization and will benefit the customer by increasing availability, and lowering intervention time and cost.

Industrial remote access devices are also providing remote support for PLC and HMI maintenance allowing a secure connection to the feeder. The access point can limit authorization only to specific devices, such as the PLC and HM of the feeder, restricting access to the industrial network for cybersecurity purposes. Connection to the system can be accomplished through the local network, wifi or a dedicated 4G network. Programs can be updated as new features become available, or more automation is requested remotely.

CONCLUSION

Mold flux feeding equipment is a known and accepted technology in steelmaking. The feeder has been further developed with sensors and automation that are presenting additional opportunities beyond consistent flux feeding. The data from the sensors manifest events in real time that can impact steel quality and operational performance of the continuous caster. The Industry 4.0 objective for the feeder is to bring the information from an isolated environment for increased analysis, automation, diagnosis and monitoring.

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