MOULD LEVEL SYSTEM UPGRADE AT DOFASCO'S #1 CASTER [1]

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Abstract
Due to the often competing interests in every steel shop of increased productivity and improved quality, steelmakers require solid/stringent guarantees from their equipment suppliers including those for the critical mould level control system. The clearly defined scope, requirement, and performance guarantees of the Dofasco #1 CC mould level system led to the development and implementation of innovative systems, technologies and equipment by the OEM (SERT) in addition to their standard equipment supply to give the performance improvements.
Key words: Continuous casting; Mould level; Eddy-current sensor; Stopper driving.

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1 INTRODUCTION

Dofasco installed a new mould level system in 2007. This discussion will describe the initial need and requirements, the benchmarking, the project itself with its innovations and the process of risk mitigation. In addition the results of the commissioning, start-up and resulting performance improvements will be reviewed.

2 BACKGROUND

DOFASCO was in 2006 in the process of implementing a Steelmaking Improvement Program project. Part of the project was to meet the future demanding customer quality standards. After consulting all major players in the Continuous casting manufacturing business, it was determined that an upgrade of the mould level system would be an enabler to that goal. By doing so, it was possible to increase mold level flatness, process data reliability and possibly productivity.

The level of the steel in the mould is maintained at a constant position by use of an automatic mould level control system. The steel meniscus level is expected to be 100mm below the top of the mould. The mould itself is vertical with a height of 904mm.

The system was composed of an eddy current measuring head (the sensor), hydraulically operated stopper rod actuator, bronze-bushing stopper-rod mechanism and PLC driven signal processing control system. A new Rockwell PLC control system had recently been installed.

The stopper rod mechanism and actuator were modified in-house for this application from the original set-up, which involved both stopper rod and slide-gate control. The response times from the hydraulic stopper rod mechanism were slow (1-3 secs).

The actual sensor device was manually clamped to the top of the narrow side copper plate. The head itself was 135mm from the narrow face and therefore moved in and out with the copper plate during width changes. It therefore also oscillated with the mould and this had to be compensated for. Its position relative to the SEN therefore changed with the cast width. In addition, the angle of the sensor relative to, as well as its distance away from the meniscus changed during a width change since narrow face taper would be adjusted at this time.

Because of this location, during any mould anomaly or SEN and tundish changes the sensor head had to be removed by the operator, the auto-level control defaults to manual and the operator must maintain the level by use of the stopper rod manual lever.

There were constant modifications to the PLC software as well as the amplifier to compensate for the performance of the system as well as interferences from other sources.

Prior to the new system installation, the original system was not responsive enough to give the control that was required and there had been a number of instances of mould powder inclusions that have been linked to high variability in the mould level. This led to slow downs on many occasions, leading to shop delays, in order to compensate for the behavior of the mould level. The stopper control mechanism was 20 years old and was adapted in-house from the original system which involved slide- gates. The stopper-rod assembly was composed of a hydraulic actuator and a bronze bushing based mechanism. Those devices were in good conditions as regular maintenance had been conducted. In addition, the sensors were constantly being rebuilt internally and as such had a very low life.

Reducing the variability of the steel meniscus level through improved mould level control will reduce the likelihood of mould powder inclusions because of instability at the meniscus.

It was expected that a new, modern mould level control system would provide uninterrupted level control and better mould level flatness with fast response times.

3 REQUIREMENTS/NEEDS

It was decided to design and install a completely new, modern mould level control system. This new system must:

- Be fully automatic
- Maintain the level to ± 3.0 mm at the most turbulent part of the mould
- Improve control and stability of the mould level
- Include or be able to include specific control strategy to match specific flow control perturbations
- Minimize the need for the operator to manually intervene or handle the sensor
- Interface with the existing Level 1 system
- Integrate with future mould design
- Reduce shop delay time caused by poor mould level control
- Have increased reliability of the various components
- Be sustainable for the next twenty years

4 SCOPE OF REPLACEMENT

The new automated mould level control system involved a complete redesign and replacement of all associated equipment and control software.

The location chosen for the sensor was specified by the vendor and must be such that non-steady state casting events changes can be done while remaining in automatic level control. The rod mechanism will continue to be mounted to the tundish and all other equipment will be located appropriately in discussions with the vendor.

The automated mould level system includes the following:

- A new sensor head
- A new sensor mounting mechanism in a location that is easily accessible and does not require the operator to install/mount.
- The new stopper rod mechanism that will be easy to set up and mounted on the tundish with low maintenance.
- Stopper rod actuator
- Stopper rod signal processing (including positioning, feedback and regulation)
- New control logic, algorithms and operator interfaces
- Completely new wiring/cabling and power feeds.
- Mould level control must be ± 3.0 mm at the most turbulent location in the mould with a response time in the order of 0.10 seconds.

- The mould level will be controlled at a nominal meniscus height of 100mm below the top of the mould.
- The system should be compatible with possible future electromagnetic mould flow devices.
- All SEN and tundish changes should be done with no manual repositioning or reinstallation of the sensor
- System should have capability of automated start cast
- System should allow for dithering of the stopper rod (for prevention of upper nozzle clogging / stopper rod tip alumina buildup)
- The system should be capable of meniscus level set-point adjustments.
- System to have functionality to dampen fluctuations due to such events as the bulging due to the effect of rolls.
- System should have a clogging prediction indicator and tracking capability.
- The ability to easily troubleshoot any problem both on and off-line, set-up and recalibrate the system and sensor as required.
- The system will interface with the existing control systems (Level1 and Level 2).
- The automatic and manual modes of operation will be designed to consider abnormal operations such as a mould overflow

5 EVALUATION OF ALTERNATIVES

A process of evaluating both the existing technologies as well as potential vendor / integrators was done and it was determined that no one technology met all of Dofasco's specification criteria as a stand-alone unit.
The majority of the vendors recommended a suspended Eddy Current sensor as the primary sensor. A comparison of some of the technical aspects of the different sensors is shown in Table 1.

Table 1 – Comparison of sensor options

	Suspended Eddy Current	**Electromagnetic (Ledge Mounted) Eddy Current**	**Radioactive**
Accuracy	+/-1 -2 mm Measures "single point" No system averaging.	+/-1 – 3 mm Measures "global mould level", or "broad surface of steel" 300mm about its axis. Wide field averaging.	+/- 3 mm Measures over 25mm wideX200mm deep area, averaging 1000 data points.
Location	Sensor can be placed at the point of greatest turbulence	Sensor fixed at one location usually at the centre of mould	Embedded in mould water jacket and continuously monitors the level
Response time	100ms or less	100ms	**180ms** with amplifier, 10ms w/o amplifier and Supplier's PLC/amp.
Mould powder affects	None	None	Yes, it picks up mould powder but this can be filtered out through software program
Auto start/auto stop capabilities	Yes (to a depth of 200mm)	Yes (to a depth of 100mm-recommended)	Yes (to a depth of 200mm+)
Accommodates EMFD	Yes	No	Yes
Maintenance Flexibility	Robust modular design and can be changed during casting.	Can only be changed with a mould exchange.	Can only be changed at end of cast.
100% of time level monitoring	No (removed during tundish fly, SEN change)	Yes (fixed position, not removed during casting)	Yes (fixed inside mold, not removed during casting

A comparison of the hydraulic versus electrical option for the stopper rod mechanism control was also done. Table 2 outlines the comparison.

Table 2– Comparison of stopper mechanism actuator options

Actuator Type	Advantages	Disadvantages
Hydraulic	• Greater downward force	• Higher cost hydraulic system • Response time > 400ms • Hydraulic fluid in steel area • Hydraulic hoses required on tundish car • Higher TCO/additional troubleshooting resources
Electro -Mechanical	• Easily interchangeable • Low maintenance • Constant performance • Not affected by temperature • No fire risk (no oil) • Response time < 85 ms • Only rolling (no friction) • Auto calibration included (pre-designed for autostart)	• Periodic electrical cable replacements as standard maintenance PM.

All vendors could provide new logic to support the equipment.

6 CHOICE OF EQUIPMENT AND OEM/INTEGRATOR

The project team decided to choose SERT Metal based in Lyon, France as OEM/integrator. This decision was based on the combination of:

- technology
- dedicated and specific expertise
- local support availability by US subsidiary (SERT METAL USA)
- guarantee of long term sustainability
- track record in supplying mould level equipment.

Based upon the technical discovery, there was an opportunity to remove the hydraulics from the system and replace it with a highly reliable electric servo system that is industry proven (benchmarking both locally and in Europe).
In addition, there was expertise within SERT in finding solutions for outstanding issues which were discovered in the engineering phase.
During the final design engineering phase the SERT subsidiary, AVEMIS, proposed a new eddy current sensor and a fully digital amplifier of its own design and development. Because this was unproven there would be rigorous testing both at Dofasco and in Europe to assure industrial capability. The technology involved in these devices was discussed with the Dofasco technical people and it aligned with the thinking about how the design of this equipment should be approached.

The new sensor system was to be validated with the following criteria:

- equipment will perform as specified in the guarantee or better
- no change in original schedule
- all equipment will be tested in the factory, and in long-term site trials in order to mitigate risk
- Dofasco technical experts would have access to each stage of sensor design and development to control schedule, mitigate technological risk and maintain the team approach taken early into the project.

Although the decision on this new sensor and amplifier was made late in the engineering and design phase, the fact that the project would now be driven by a single source OEM would simplify the project structure and give better insurance of supplier's accountability. It was also believed by the project team that a superior technology was now achievable, and it was decided that Dofasco would not take the risk to upgrade its caster with near-obsolete technology.

The sensor system was fully hot-commissioned in February 2007, well before the shutdown when the whole system was integrated. This hot commissioning occurred shadowing the existing sensor process, with no effects to the casting operation.

This mitigated any sensor related start-up risks.

SERT recommended that the sensor be located in a fixed position near to the SEN. This meant a change from the existing mounting on the top of the narrow face, which moved with the narrow face (and tilted with the taper changes), to an orientation where it was mounted on the broad-face side of the mould cover.

By using this new digital amplifier, Dofasco was in a position to be flexible with respect to the choice of the sensor. If a traditional sensor supplier's amplifier was used, Dofasco would be bound to that supplier's sensor. This feature was validated during testing.

In addition, the new digital amplifier allowed:

- Compensation for oscillation of the mould to be done in the frequency domain with minimal 'time response' penalty
- The entire system to be immune to electrical noise
- Better resolution of level
- No need for tuning of Analog transmitters and receivers which meant a drift free signal (the calibration procedure is simple with a friendly human machine interface)
- The design is up to date and open to future functionalities (as field-bus connectivity, mould flux level measurement, EMS magnetic field measurement…).

Field trials with the new AVEMIS sensor showed a superior performance to the traditional eddy current sensor. Some of these results are shown below:

Table 3 – Results of comparison test of sensors

	Commercial Eddy-Current Sensor	New SERT Sensor	Existing Dofasco Sensor
Ultra Low Detection	200 mm	240mm	150mm
Repeatability	0.1 % F.S.	0.1 % F.S.	1.0% F.S.
Linearity	1.27 % F. S.	1.2 % F.S	1.5% F.S.

In addition, the AVEMIS sensor was run in parallel with the existing sensor through the same electronics and control and it demonstrated that it could sense the level 1.2 – 1.5 s faster than the existing sensor. Figure 1 hereafter is the actual trace recorded in the testing.

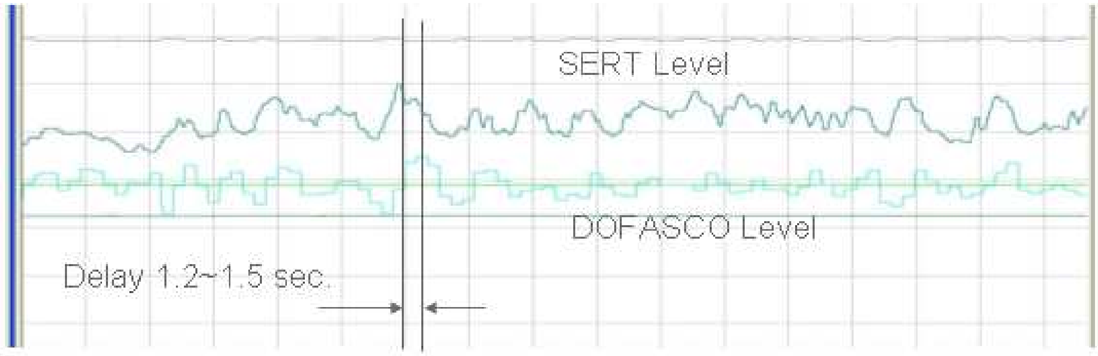

Figure 1 – Mould level values during test of trial and existing sensors.

To fulfill the requirement of minimal manual intervention by the operator, AVEMIS designed a sensor manipulator, including integrated software, which had the capability to automatically insert and retract the sensor over the mould.
As a result, there were two methods of inserting the sensor over the mould. The first was a manual attachment on the mould cover by means of a bracket that was welded to the cover as well as the automated manipulator system.

7 THE NEW MOULD LEVEL CONTROL EQUIPMENT INSTALLED

- A new Controller:
  - Includes a new PLC integrated into existing network
  - New control software
  - New advanced functions loaded on a specialized PC (as surface waves auto-adaptive filtering, speed feed forward…)
  - Digital amplifier
  - Faster response

- An Electrically Actuated Stopper Rod Mechanism
  - Easy to maintain
  - Easy to calibrate
  - Guaranteed no hysteresis (unlike current bronze-bushing system)
- An Electrical Actuator With Brushless Motor
  - Removable
  - Self calibrating
  - No maintenance required
  - Ability to monitor internal temperature
  - Response time <85ms (current system is >500ms)
- A New Eddy Current Type Suspended Sensor
  - 3-coil sensor
  - Long lasting (1 year vs. 1month)
  - Minimal oscillation compensation delay
  - Improved internal cooling to avoid temperature drift
  - Ability to monitor internal temperature of the sensor
- New Digital Amplifier
  - 100% digital signal treatment
  - Profibus / Ethernet IP connectivity
  - Minimal maintenance with no wearable parts or need for potentiometer adjustments
  - Easy calibration (less than 1à minutes, no oscilloscope or PC needed)
  - Open to future functionalities (easy firmware update)

Features of the new equipment include:

- Fast reaction to sudden or strong perturbations
- Sensitivity and accuracy (±1 mm)
- Sensor internal scanning time - 1.56 µs and output sampling time -10 ms
- Stopper rod dithering
- Adaptation for tundish level variation
- Accommodates for cast speed and width
- Package of parameters, from experience, to optimize control performance
- Set-point setting and adjustment
- Stopper rod emergency close
- Clogging rate predictor and index
- Controlled stopper flushing (bumping)
- Stopper system checks
- Quality index ratings depending on mould level
- Software module that compensates for and reacts to strand bulging effects
- Software module that filters surface waves
- Software module that reacts to clogging by altering speeds and allowing cleaning
- Strand auto start
- Data storage, event logging and analysis, troubleshooting, charting

8 PROJECT SCHEDULE AND TEAM APPROACH

The schedule was driven by the need to install the system during the planned shutdown in May 07. This required a concerted effort on the part of the Dofasco project team as

well as the SERT organization because of the relatively short time between the award of the contract (Fall 06) and the installation date. Subsequent planned work for the preceding shutdowns (November 06, January 07, and March 07) allowed for a seamless integration and vertical system start-up after the May 07 shutdown.
During the engineering phase it was realized that, due to the new technology that was going to be used as well as the scope of the project, Dofasco and SERT had to work more closely together as a team. This team approach, which was new for the OEM, was very successful in maximizing collaboration for the purpose of better technical exchanges, reducing the technical risk and increasing the innovative capability of the group.
The project was formally structured with three engineering review phases, and two acceptance tests. There was also a proof of concept/technology test of the proposed new AVEMIS sensor and amplifier prior to final agreement of the contract. As a result, the project has been able to mitigate the additional risks to the original project of having the OEM switch sensor from the traditional to the new AVEMIS type as well as develop the automated sensor manipulator. That part was then de-coupled from the rest of the project in order to schedule trials and extra testing.
The main steps of the project are outlined in Table 4.

Table 4 – Summary of the project schedule

Landmark	**Completion**
Basic engineering review	July-06
50% engineering review	August-06
100% engineering review	September-06
Start procurement / manufacturing	September-06
Sensor hot trials (shadow)	November-06
Construction work/ pre-cabling	January-07
Sensor site testing and hot commissioning	February-07
Factory Acceptance Tests (FAT)	March-07
Off-line commissioning	April-07
Pre-shutdown commissioning (SAT)	May-07
5-day shutdown	May 14 - 07

9 RESULTS

The system was fully installed, integrated and commissioned during a shutdown in May 2007. There was a vertical start-up with no issues. The manual sensor was used initially but the automated manipulator was quickly put into service and has been running, with minor interruptions since then.
The performance guarantees were achieved within the first week and appropriate sign-offs were done.
The performance of the system can be characterized in the three main categories shown below.

9.1.Control

- Mould level has improved both in terms of absolute level and variability (See Figure 2 below).
- Faster response of sensor (0.8 seconds old system, 0.4 seconds new system). The new sensor provides real-time filtering for the oscillation, while old sensor used a filter that slowed down the response
- Sensor is not mounted on the oscillating part of the mould
- Faster response of the stopper mechanism actuator (0.5 second old system, less than 0.1 second new system)
- Optimized controller behavior with dedicated strategy to match perturbation
- Mould level stays in Automatic control more often (about 6 times per day auto would be lost previously due to extreme mould level fluctuations - These are essentially eliminated.)

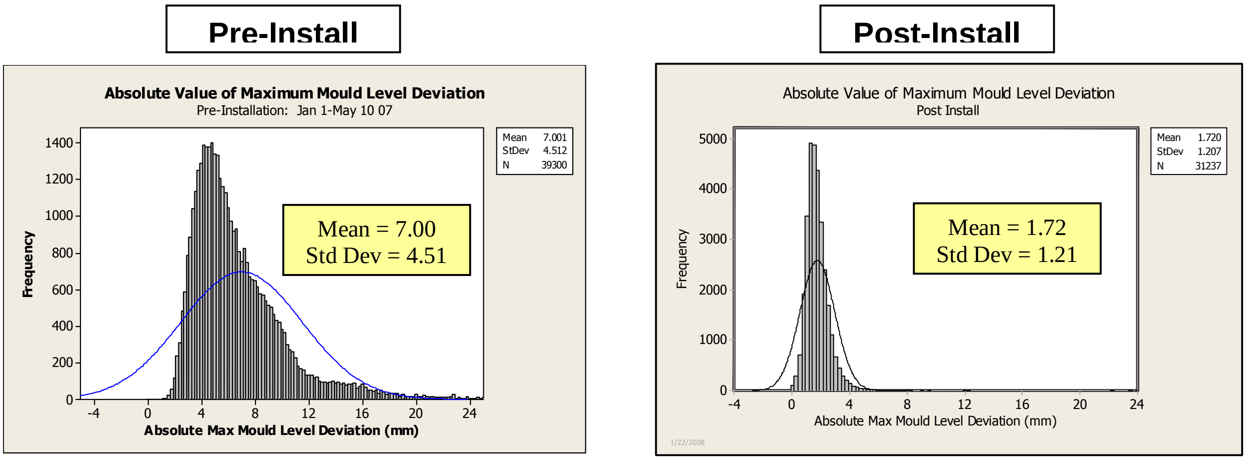

Figure 2 – Comparison of mould level performance before and after installation of new mould level system.

- The response to clogging and washouts was improved as shown in Figure 3:

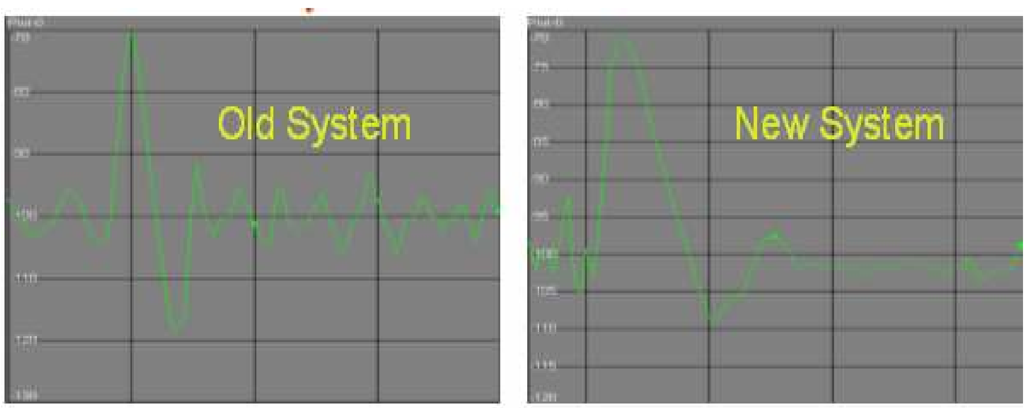

Figure 3 – Comparison of stopper rod washout response.

As seen in Figure 3, the original system responds very quickly to washouts but then over shoots the target and goes into an oscillation hunting for its target level while the new system responds in a controlled manner but does not overshoot the target as far (10 mm versus 20 mm) and the process is stable. Rapid rates of change in mould level are known to cause slab defects by entrapping mould powder.

9.2. Stability

- More stable mould level control --- No drift of level (Stays within +/-15 mm during width changes, speed changes, grade changes etc)
- Operator is more comfortable – able to concentrate on other parts of the caster operation
- No drifting of the sensor reading
- No drifting in stopper mechanism actuator characteristics
- No recalibration for width speed or grade changes

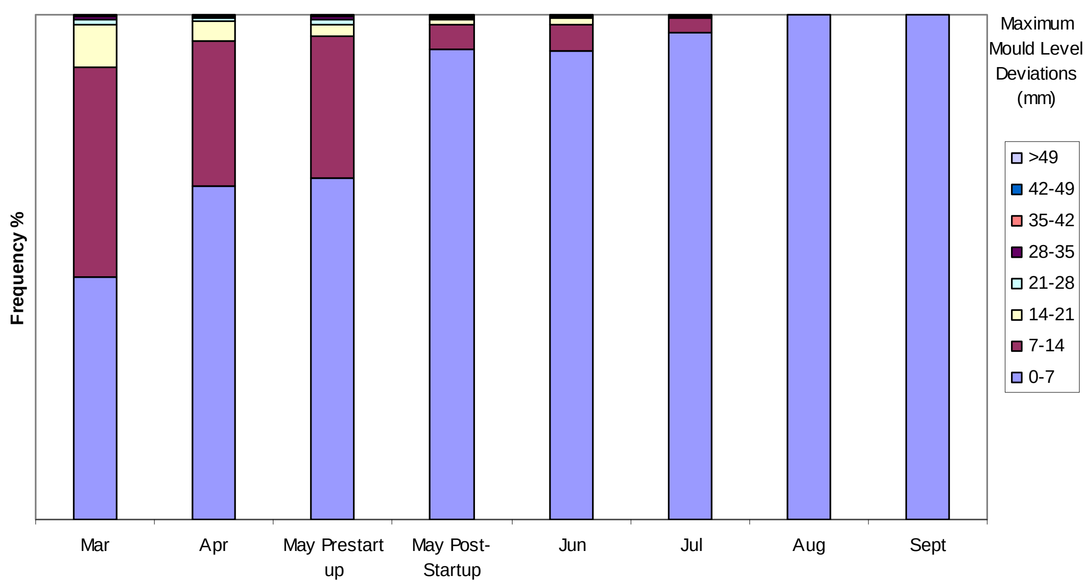

Figure 4 – Maximum mould level deviations from aim In 2007.

This Figure 4 shows the categorization by the maximum mould level deviation within a slab for all slabs for the month. (For example, the 0-7 mm group shows the % of slabs with a maximum deviation any where from 0 to 7 mm)

a. Maintenance

- No potentiometers to adjust, wear out, replace
- Easier calibration for the operator
- Maintenance calls for sensor re-calibration have been reduced from about 3 per week to essentially zero
- No operator handling of the sensor (due to manipulator)
- No dunking of sensor in the mould bath – auto retract on High-high level.

- Currently using the original (start-up) sensors and actuators.
- Improved temperature control of the amplifier and the sensor
- Stopper mechanism internal bushings were upsized by SERT since start-up to account for the greater loads on the mechanisms. This mechanism design is the ultimate extra large model from SERT because of the large size, based on similar SERT previous designs for smaller tundishes. No specific maintenance was requested on the mechanisms and actuators since start-up.

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