Automated industrial slab surface inspection system, based on contactless technologies

*Système industriel d'inspection automatique de la surface des brames, basé en technologies sans-contact*

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1. Short abstract

A novel system for on-line longitudinal cracks and marks detection in hot slabs has been installed in ArcelorMittal continuous casting plant in Avilés (Spain). The system is fully industrial, has been integrated in the plant process without any alterations to it’s throughput, and is giving high quality results that are helping to enhance the productivity of the plant.

*Un nouveau système de détection en ligne des fissures et marques longitudinales dans les brames chaudes a été installé en usine dans la coulée continue d’ArcelorMittal en Avilés (Espagne). Le système est pleinement industriel, il a été intégré au processus de production sans modifications fonctionnelles, et il donne des résultats de haute qualité qui contribuent à améliorer la productivité de la plante.*

2. Extended summary (French)

3. Introduction and Objectives

This paper presents a new industrial system, based in Conoscopic Holography technology (C.H.), that ensures the 100% of inspection of longitudinal cracks in the two wide faces of hot slabs produced in continuous casting. These cracks (figure 1) can appear in specific steel grades with certain process conditions, and are harmful for the surface quality in downstream processes.

*Figure 1. Photographie d'une fissure longitudinale*
The usual way to inspect these defects is to cool down the slabs to ambient temperature, and send them to a manual inspection station where manual operators check and, if needed, repair the surface by means of scarfing. This operation consumes valuable resources, and for a high percentage of slabs would not be needed as they are found to have no defects.

The presented inspection system overcomes these inconveniences, by means of an automatic evaluation of the surface quality done in hot product, while it travels over the evacuation strands, with scale present, and without any changes of the process throughput. The result of the inspection is a detailed map of the location of longitudinal cracks larger than 100 mm, able to be used in less than 20 secs after the slab has been fully inspected.

With this purpose, two inspection systems have been constructed and installed by a consortium integrated by Desarrollo de Soluciones Integrales Plus, ArcelorMittal Spain R&D and University of Oviedo, in collaboration with IngeTeam. The inspection systems have been installed in the slab evacuation lines at ArcelorMittal Continuous Casting plant (Acería LDA) in Avilés-Spain, just after the deburrers (figure 2). A 100% of the production is inspected with these systems, and on-line decisions according to the results of the inspection are made automatically by the plant’s process computer or manually by the operators. The system has been conceived so that no alteration of the process is needed in the inspection point.

Figure 2. Surface Inspection systems in the continuous casting line

This new system, fully automated and in real-time connection with the plant process computer, allows a quick and reliable assessment of surface defects. It’s fast and accurate reconstruction of defects map is a very useful tool for the steel plant, in order to decide about the route of slabs (repairing or send directly to the next installation), saving time, repairing operations, slab yard management and energy consumption.

The technical details of a partial test prototype and the basic technology have already been presented in several forums ([1], [2]). The present paper focuses in the integration of the industrial system in the plant process, and the results and benefits obtained thanks to it’s use.
The actual industrial system is being successfully used since January-2007, and is currently becoming a key point for the continuous casting plant, helping to increment both quality and productivity.

4. System Description

Currently, two inspection systems are installed in the evacuation lines, once the slabs have been cut, just after the deburrer. Slab speed in the inspection point is around 20 m/min, and temperature between 600 and 900 °C.

Each inspection system consists of a C frame – in front view - that holds the sensors and protects them against heat and dust. It can be displaced on a rail to be put on-line or off-line by automatic or manual means, enabling maintenance without affecting other elements in the line.

Figure 3 shows one of the two systems in the line.

Figure 3. Surface Inspection system on-line

The inspection system executes unattended; a computer is in charge of the automatic control of the different subsystems, and it is connected to the process computer from which it receives the inspection orders and to which it reports the inspection results.

For each wide face, 6 Conoscopic Holography long stand-off sensors, covering each one 300 mm in the width direction, obtain the surface topography of up to 1600 mm wide slabs without altering the process conditions: hot slabs moving in the evacuation lines with scale present.

The main sensing technology, phase-based Conoscopic Holography (C.H.), is an interferometric measuring technology that is able to obtain the surface topography in varied circumstances (see figure 4); in this case, hot slabs moving in the evacuation line with scale present. A deeper explanation of this technology can be found in [3] and [4].
The C.H. sensors installed for this application use 1150 mm stand-off, easing setup in the line and heat protection, with a depth of field of ±30 mm. Each sensor obtains a distance profile at a rate of 60 frames per second (5 mm resolution in the longitudinal direction at 20 m/min slab speed), with 640 points lateral resolution (0.5 mm/point in the lateral direction) and around 0.1 mm depth resolution. These resolutions ensure to reliably detect cracks longer than 100 mm, and deeper and wider than 1 mm.

For the upper side, an automatic vertical movement adapts the sensors position to different slab thicknesses, according with the information received from the process computer. For the lower side, a mirror based set-up has been developed to ensure the stand-off without any civil work in the plant. Figure 5 shows the sensors setup inside the C-frame, and a photography of the real system with the covers open for visualisation of their position.

The sensors give as output a topographic map of the surface of the slab (see figure 6). Advanced machine vision algorithms allow to discriminate automatically the scale (bright zones in the figure), the surface (mid grey) and the depressions surrounding the cracks (dark zones).
To be noted that the system detects longitudinal depressions that match with certain characteristics of width, depth, length and shape; some of them have cracks in the bottom, and some correspond to other types of surface defects, such as roll marks and other defects induced by the casting machine operations.

Accompanying these main sensors, conventional machine vision grey-level linescan cameras collaborate producing a conventional image of the surface. This image (figure 7) is interesting for further processing and for presentation to the operator, as it corresponds more directly to what is seen by eye.
The detection system is equipped with auxiliary subsystems for a heavy industrial use:

- Real-time connection with the process computers, exchanging all the information needed for operator visualisation.
- Alarms and warnings that automatically withdraw the system in case of hardware problems (high temperature, fan failure, etc.).
- Self-monitoring for detection of common problems affecting the detection: window cleanliness, objects (usually burrs) in the field of view, sensor not responding or not properly working, etc.
- A huge data-base for hundreds of thousands of slabs for off-line access and analysis of defects.

5. Current results

The inspection system has been installed in December 2006 in ArcelorMittal LDA plant in Aviles, Spain, and has been in full operation since mid January 2007.

During this time until now and 24/24 hours, more than 200,000 slabs have been inspected, with an usability over 97%.

The inspection system reliably detects longitudinal cracks and marks in the slab surface, enabling slabs classification (repair station or direct to next process) and process feedback (maintenance operations between casting sequences can be rescheduled according to online data obtained from the system).

Figure 6 has shown the typical aspect of the surface topography of detected longitudinal cracks, and figure 8 shows now the same result for roll marks.
5.1. **Applications of the inspection system**

Several benefits are obtained from this inspection system in the plant’s daily work. Some of them have a direct economic impact in the continuous casting plant, others help to reduce conflicts in downstream processes, or to improve knowledge about the process itself.

According to the steel grade, slab dimensions and on-line process data obtained, the plant’s process computer pre-classifies the slabs as “suspicious” or “direct charge”, among others.

Before the use of the automatic inspection system, all suspicious slabs (around 20% of the overall production) had to go through a manual inspection station, where they are reviewed and repaired if needed. Direct charge slabs never went to the manual inspection station.

After the installation of the inspection system, only slabs really having surface defects go to the manual inspection system. Five main benefits are extracted from this new operational structure:

1. The map of defects allows to automatically change the route of slabs suspicious to have longitudinal cracks, but not having them, from “manual inspection and repair” to “direct charge”. This saves costs of storage space and movements, manual inspection, and also energy and CO2 savings by incrementing the possibilities of hot charge in downstream processes (Hot Strip Mill or Heavy Plate Mill).

   This is by far the most important benefit for this plant; the reduction in more than 80% the number of slabs to be manually inspected allows not only to reduce costs but, even more important, to reduce or eliminate the constraint of having many casting sequences of “suspicious” steel grades, allowing to schedule more casting sequences of these grades.

2. The route of slabs not suspicious to have longitudinal cracks can be automatically modified from “direct charge” to “manual inspection and repair”, when they are found to have surface defects. This inspection was not done before, so all of them are directly sent to downstream processes; as these slabs may occasionally present
cracks or other surface defects, that finally appear in the rolled sheets or coils, quality problems in these processes can be reduced.

3. Fast on-line detection of problems in the casting machine, especially adherences in the mould or the rolls, rolls breakouts, that are producing dangerous deep and narrow longitudinal marks in the slabs. Until the start of operation of this system these defects never were detected by the operators in the lower face, and only occasionally in the upper face. The inspection system gives fast information about these problems, giving the opportunity to repair the slabs, the mould or rolls, reducing the amount of defective slabs produced and, in some cases, avoiding worst consequences in the casting machine itself.

4. It allows to have objective data that can be used for claims solving, and also for relating the casting parameters to the presence of defects, their position in the slab and their dimensions, enabling a better knowledge of the formation of defects that may lead to their reduction. Moreover, the maps of defects can be correlated with other defect analysis systems in the downstream processes.

5.2. Inspection results

Up to the moment, after more than one year of operation, no claims have been received from the downstream processes (Hot Strip Mill and Heavy Plate Mill) because of defective slabs not detected by the inspection system.

This is a very important result, taking into account that during this time more than 15,000 slabs have been released from manual inspection according to benefit 1. More than 20,000 slabs (300,000 tons) per year are expected to be released in this way.

The evolution of the system during the first year on operation is shown in the next figure, where it is shown that availability has reached 95% (availability measures inspected slabs vs produced slabs, and many factors internal and external to the inspection system can affect this measurement), and slabs released according to benefit 1 have increased up to 70% (this figure is continuously increasing thanks to improvements in the defects classification).

Figure 9. Evolution of the system during 2007

*Figure 9. Evolution du système en 2007*
Figure 10 shows two representative weeks, one from 2007 and another from 2008. Two key figures have to be noted: the increment of the percentage of released slabs (as seen before), and also how the system is helping to improve production scheduling, enabling to increment the percentage of suspicious casts. In figure 11 this increment can be seen (black skin slabs are the suspicious ones) for the first third of 2008.

<table>
<thead>
<tr>
<th></th>
<th>OCTOBER Week 43 of 2007</th>
<th>MAY Week 23 of 2008</th>
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<tbody>
<tr>
<td>Slabs susceptible produce over total production</td>
<td>357</td>
<td>14 %</td>
</tr>
<tr>
<td>Slabs released over suspicious</td>
<td>708</td>
<td>26 %</td>
</tr>
<tr>
<td>Total Production</td>
<td>2870</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Figure 10. Comparison between a week in October 2007 and a week in May 2008

Figure 10. Comparaison entre une semaine en Octobre 2007 et une semaine en Mai 2008

About deep marks in the surface, changes in the maintenance operations have been decided in more than 10 occasions thanks to the inspection system alarms. This has lead to a high reduction of slabs with dangerous marks sent to Hot Strip Mill, and in some cases probably to the avoidance of costly panes in the casting machine. Further research is being carried out in order to correlate these results with measurements of currents in the driving motors of the casting lines, so predictive maintenance can be integrated in the plant procedures.

5.3. The over-detection issue

The inspection system detects depressions with a certain configuration: longitudinal shape, adequate transversal shape and relations between depth, width and length. These depressions, as a rule, contain a crack inside, but not always. When other surface formations have the same shape they are detected as cracks, being in fact false cracks, and becoming an over-detection.

The system has been designed to have zero sub-detection, i.e., it detects every depression matching the programmed configuration. But over-detection is an important issue, and subject to parameterization: if a minimum length of depressions of 100 mm is used, many irregularities of the surface may appear as cracks, and the efficiency of the system for
benefit 1 (the principal for this plant) is much lower. If minimum length of depressions is higher, the efficiency of the system for benefit 1 is much higher, but the result could be a sub-detection of some important defect.

The tuning of this over-detection is being performed by plant engineers, with the trend of reducing the over-detection while maintaining zero sub-detection. Several new parameters have been extracted since the start of operation, being resumed as crack relevance, that allow to reduce over-detection not taking into account depressions that are known to be not dangerous due to their shape.

6. Conclusions

This surface inspection system for longitudinal cracks in C.C. has been industrialized, and is currently in operation at Arcelor Mittal LDA in Aviles, with very good results.

Inspection results and usability have converted this system in a key competitive improvement for the plant, reducing operational costs, incrementing products quality and process knowledge, and helping to improve maintenance procedures.

It is remarkable that modularity of CH sensor and flexibility of software, allows an easy adaptability to the needs of other steel plants.

Research in this technology continues, in two main aspects: adaptation to faster processes, that will enable to introduce higher level of product quality assessment in other steel facilities; and adaptation to higher resolutions, enabling to measure small defects or roughness parameters on-line.

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