Surface inspection in hot steel products using Conoscopic Holography

Ignacio Alvarez (1), Jorge Marina (2), Ricardo García (2), José M. Enguita (1)

(1) Universidad de Oviedo. Ing. de Sistemas y Automática. Campus de Viesques - 33204 - Gijón - Spain
(2) Desarrollo de Soluciones Integrales Plus S.L. C/Cirujeda 12 – 33205 - Gijón – Spain

Summary

Early surface defects inspection in hot steel products is more and more necessary in steel production lines, as it can help to reduce significantly production costs and clients rejections.

Most of the commercially available systems for on-line inspection use imaging as detection technique, but in harsh environments this leads to low reliability and very difficult defects classification, as surface formations that should not be considered as defects may give similar images that can not be distinguished by an automatic system.

Conoscopic holography (C.H.) is a profilometric technique, that is, its output is the surface distances profile of the inspected object. That way, this technique is able to recover new information that is helpful to classify defects more reliably in harsh conditions.

The paper covers the principles of the technology, its application in a steel continuous casting facility for surface cracks detection, working in plant conditions for almost 3 years, and other potential applications currently under development.

Keywords

Conoscopic holography, automatic inspection, route decision.

Introduction

Two Surface Inspection systems (SURFIN) based on C.H. are in 24h/24 production since January 2007 in ArcelorMittal's Continuous Casting plant in Avilés, Spain (figure 1). These systems are able to detect longitudinal surface cracks in the steel slabs once they have been produced, at a temperature between 600 and 900°C and without removing scale [1].

These systems have been fully integrated in the plant production scheme, as they don't alter the plant's throughput, while they allow on-line automatic slab route decisions (direct charge or repair) made by plant computers.

By using the inspection systems, this plant has obtained 4 main benefits at the same time:

- Operational costs reduction, as only the defective slabs follow the repair route; previously, all the suspicious slabs (depending on steel grade and production parameters) had to follow the “manual inspection and repair” route, where a high percentage of them (above 90%) were manually checked as non defective.
Downstream claims reduction, as many defects were previously not detected for direct charge slabs (for instance, longitudinal marks due to roll jams).

Production mix improvement, as it was previously conditioned by the slab yard space available for suspicious slabs, that usually correspond to some specific steel grades.

Improved process knowledge, thanks to an objective inspection tool with an associated database that can be reviewed by plant engineers.

**SURFIN principle of operation**

The underlying technology for the cracks inspection is Conoscopic Holography (C.H.). A C-frame holding Optimet's Long Stand-off Conolines (figure 2) is installed in the evacuation lines, just after the deburrers.

Each Conoline sensor is placed at a safe distance of 1150 mm from the slab surface (top and bottom), and is able to obtain distance profiles with 0.1 mm depth and 0.5 mm lateral resolution of a 300 mm stripe of the surface, at a rate of 60 profiles/second. To cover the full width, 6 sensors are needed in each side for this case.

The sensors automatically detect the presence of a new slab, and start acquisition and processing of it's surface topography until the slab surpasses them. The normal advance of the slabs in the evacuation strand, at 20 m/min, is used without
any modification (speed in that point is low due to the proximity to the deburrer); this leads to a resolution of 5.5 mm in the longitudinal direction for each profile.

As output, each sensor generates a topographic map, where the normal surface has grey colour, depressions are seen as dark zones and the scale (over the surface) is seen in light colour. The images from all the sensors are combined, and specialized machine vision algorithms are applied to detect longitudinal depressions that usually hide cracks (figure 3).

Figure 3. Results of a scan with the depressions detected.

For comparison, an image of the same defects is obtained by a greylevel linescan camera (figure 4). Due to the presence of scale (that is not removed) and the low contrast of the depressions, the accurate detection of these defects in the greylevel image is completely unviable.

All the defects detected are automatically measured and classified, and sent to the process computer no more than 15 seconds after the slab has surpassed the inspection system. The process computer uses the results of the inspection, together with other process information, to determine whether the slab has to go to manual inspection or can continue to direct charge.

Everything is stored in a database, so plant engineers can solve claims from downstream processes, elaborate statistics, or generate new knowledge that can help to reduce the presence of defects.
The technology: Conoscopic Holography

The underlying technology used by these sensors is Conoscopic Holography, an optical interferometric technique that uses double refraction properties of uniaxial crystals [2]. When a ray of polarized monochromatic light crosses a uniaxial crystal, it is divided in two rays (ordinary and extraordinary) that travel at different speeds inside the crystal, and that can be combined to interfere in a detector; as the speed of the extraordinary ray depends on the angle of incidence, the interference figure formed is dependant on the distance of the light emitting point (figure 5).

As the interferogram has radial symmetry, only one line is needed for processing. By using the appropriate optics, it is possible to obtain in the rows of a matrix CCD sensor the interferograms of a line of light reflecting points, when illuminated with a laser line (figure 6). To obtain the distance, the frequency and/or phase of the interferometric rows must be calculated.

Figure 5. Principle of the conoscopic holography
Due to its inherent colinearity (although a very small triangulation angle is used in long stand-off configuration), and the robustness of the interferometric signal regardless of the type and orientation of the surface, this technology is very appropriated for dimensional inspection in harsh environments: heat, dust, etc.

**SURFIN results in operation**

After more than 3 years of operation in two evacuations lines, 24h/24 the system is consolidated in the plant production scheme, and its on-line evaluations are used for automatic decision of the route of slabs. During this time, more than 300,000 slabs (more than 6,000,000 Tons of steel) have been inspected, with more than 95% usability.

The system is tuned to favour overdetection, that is, it is in the conservative side: if there is a clear depression with certain shape, a defect is marked. Plant operators have been tuning the system to reduce the overdetection without arriving to undertecction; with this policy, no claims have been received so far of undetected defects in downstream processes.

Every depression can be detected by the system, so it’s also being used to detect longitudinal marks due to roll jams (figure 6). This type of defect was previously not detected until the slabs were rolled and inspected in the Hot Strip Mill. Thanks to the fast response, the plant can clean up these slabs and also decide to repair as soon as possible a jammed roll in the casting machine, reducing the amount of defective slabs sent to the HSM.
A key fact of this technology is that the interferometric signal carries more information than the distance: the signal to noise ratio and the luminosity are also usable for improving the search. In this case, these data are used to reduce the overdetection, eliminating incorrect results due to excess of scale, shiny surfaces, dust or scratches in the protective windows (specially in the lower side), falling scale or undulated surface (figure 7).

![Figure 7](image)

Figure 7. Some formations that should not be detected as defects are removed when processing auxiliary data as luminosity and snr: excess of scale (a), scratches in windows and shiny surface (b), falling scale (c) and undulated surfaces (d).

**Other applications of Conoscopic Holography in surface inspection**

The same physical principle, only changing the optical setup, can be applied to other inspection situations, both in cold and hot targets [3].

An adaptation of the current system has been designed for hot seamless tubes at 1000ºC, in order to detect shape defects formed in the intersection of the 120º rolls. Lab trials were performed with samples heated in an oven, where the shape defect was clearly detected (figure 8).

![Figure 8](image)

Figure 8. Results of detection of shape defect in steel tube: analyzed sample (left), distance map (rectified for clarity) in cold conditions (centre), and the same map in hot conditions (right). The real depth of the defect (measured with CMM) is less than 0.2 mm.

Work is being carried out to perform submicron measurements in steel and other materials. In the case of steel, roughness measurements in galvanized plates have been obtained in the lab with a resolution similar to a contact stylus (figure 9).
This system is also valuable for other industries, as the semiconductor, as it is able to recover even defects in nanometric scale (figure 10, left).

Other systems using simpler punctual probe configuration have been developed for measuring shape in cylindrical automotive pieces (figure 10, right), and vibrations in hot targets (RH treatment in secondary metallurgy).

Current trends

The major limitation of the C.H. profilometer is its speed, as the actual device’s maximum throughput is 60 profiles per second, with 640 points per profile. Most of the industrial processes requiring surface inspection need higher speeds for on-line detection.
An upgrade of the current sensor able to output 350 profiles per second (each one with 1400 points) is expected by April. This sensor could address traditional steel industry surface inspection problems, as the corner cracks detection in casting lines.

A new configuration, able to deliver up to 3000 profiles with 4000 points each, is under research (figure 11). First lab results are expected by the end of the year. This configuration would enable to improve detection and classification of defects in faster lines, as Hot Strip Mills.

Figure 11. High speed conoscopic system under research

**Conclusions**

The recuperation of surface topography for surface inspection applications can give invaluable new data for image processing algorithms, especially in harsh conditions or low contrasted defects. Conoscopic holography has proven to be an outstanding technique in harsh conditions (heat, dust), and it’s usability and robustness in production plants has also be proven.

Other applications are open, in the steel and other industries, for which faster new C.H. sensors to be developed during 2010 will bring solutions in the next future.

**Acknowledgements**

Parts of the research contained in this paper have been financed by the Spanish Government (project ref. DPI2007-64243), and the Asturias Regional Government (project ref. IB08-051). The authors wish to thank these institutions for their support.

**References**

