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TOPOGRAPHIC SURFACE INSPECTION SYSTEM FOR SLABS*

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Abstract

3D-Measurements for slabs and heavy plate are now available and close the gap in the production chain. The measuring systems described in this presentation must be seen as high-tech solutions in the field of casting and rolling technology. The measuring systems were developed taking into consideration the harsh casting and rolling mill environment in which they are to be used, with the aim of achieving high operational reliability and eliminating disturbances. Interconnected quality management systems enable optimization across the complete production process. New limits are being defined constantly for all these developments. What is technically feasible today becomes normal practice tomorrow, and will probably be replaced by completely new technologies the day after.

Keywords: Automated surface inspection; 3D and 2D surface inspection; Continuous casting; Steel slabs; Crack detection; Defect depth inspection.

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1 INTRODUCTION

The improvement of both rolled strip surface quality and geometrical tolerances constitute one of the major challenges facing the steel industry [1]. Surface qualities along with other properties are the most important quality parameters, particularly for flat-rolled steel products. Therefore it is vital for the quality of the final product that the product surface be inspected throughout the complete process route from continuous casting through to the finished coil or plate. The essential pre-requisite for attaining the high quality of product is the use of new measurement and control technologies for production [2][3].
Surface defects may arise either in the cast slab and emerge during later processing stages, or stem from the rolling process itself and are strongly affected by the condition of the mill components, the stand behaviour and by the process control. Whereas defects originating in the slab must be mainly reduced by the optimisation of casting conditions and by slab scarfing, the prevention of defects stemming from rolling requires advanced strategies for process and plant management within the hot and cold rolling mills.
The steel slabs produced in a continuous caster are susceptible to a variety of surface imperfections including: longitudinal surface cracks, transverse surface cracks, frontal cracks, collar, corner and edge tears, scum patch, scum pits, scum tear, bleeder and rapeseed scab. These defects have to be detected before the subsequent rolling process in the finishing mills. So, an inspection stage between casting and hot-rolling is needed to detect and remove injured slabs [4].
Hot charging has made defect awareness and detection in the continuous casting of steel a more important problem than in the past. If slabs coming off the caster are inspected, thermal units will be lost, and if slabs are passed, unchecked, the risk is higher that finished product quality will be unacceptable to the customer and higher costs will be incurred. It would seem clear that the best approach to the situation is an accurate predictive tool that provides for the confidence that only high quality slabs are passed to the hot rolling mill [7].
This report will present the new inspection technology in the continuous casting process.

2 STATE OF THE ART – A SHORT REVIEW

To ensure stringent requirements of customers, automated vision-based steel surface inspection techniques have been found to be very effective and popular during the last two decades [5]. Surface inspection systems must be able to detect such defects that might cause harm in subsequent processes. They must be able to know which defects are crucial with respect to subsequent processes and their quality requirements. They must be able to exchange this production expertise across multiple production lines in order to enable both feed-forward and feed-back control. They must be able to be integrated into a holistic surface quality yield management landscape, which fits into the holistic approach to operational excellence [6].
Therefore particular notice needs to be taken to the presence of scale, which constitute a brittle, often cracked, top layer, formed from oxidization in the manufacturing process. This scale layer is unavoidable during casting, and cracks therein are from a top view perspective similar to cracks in the steel and therefore risk causing false positives in the detection result [8].

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For automated steel surface inspection systems commonly gray-scale intensity imaging is used, in combination with various different signal processing techniques such as wavelet transforms, Gabor filters and image morphology.
But the benefit of gray-scale intensity images in the presence of scale is limited: Variations in lightning conditions may lead to potential pseudo-defects. In particular, light reflection from scale regions may vary substantially, making the gray level in intensity images highly unpredictable.
To overcome these problems in the presence of scale, where surface defects may have “three-dimensional characteristics”, range imaging is applied. Range-imaging sensors collect large amounts of three-dimensional (3-D) coordinate data from visible surfaces in a scene and can be used in a wide variety of automation applications, including object shape acquisition, bin picking, robotic assembly, inspection, gaging, mobile robot navigation, automated cartography, and medical diagnosis [9].
In [8] a strategy for morphology-based crack detection for steel slabs based on 3D surface profile data collected by laser triangulation is presented.
An advanced technology for hot slab surface inspection has been developed and installed in ACERALIA (Spain) [10]. The system, integrating Conoscopic Holography, CCD cameras, a complex mechanical system and intelligent tools, is able to determine the slab quality level in real time [11].

3 SURCON X-3DVISION – COMBINED 3D AND 2D INSPECTION OF SLAB

The X-3Dvision system from the Surcon GmbH combines 3D and 2D surface inspection. The System is suitable to inspect slabs immediately after the continuous casting process, Figure 1. It was developed to detect and classify surface defects such as cracks, inclusions, or mechanical indentations. The system generates both a 3D and a 2D image of top, bottom and edges of slabs surfaces. These images are instantly checked for any surface anomalies. In doing so, the system not only captures the area but also the depth of the surface defects. At the same time, the edge contour is inspected in order to obtain information about any edge defects as well as about the shape and the width of the slabs. X-3Dvision works in real time, instantly delivering information about the condition of the slab.

Figure 1: Inspection system in the caster

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4 BENEFITS OF AUTOMATIC SLAB INSPECTION AND DIMENSION MEASUREMENT

The benefits of the X-3Dvision system can be summarized as follows:

- Automatic detection and classification of defects including position and dimension information of the defects also in depth,
- Minimizing grinding and scarfing,
- Minimizing manual inspection,
- Optimization of the continuous casting process, The combination with X-2Dvision systems for the inspection of hot and cold strip makes it possible to track the surface defects along the complete process chain,
- If the surface data are linked with other measuring data, such as geometry or material data, defect sources that have their roots in upstream stages of the process can be identified and eliminated. This is a decisive feature in achieving not interrupted quality assurance from continuous casting all the way through to the finished coil or plate,
- Complete dimension measurement of the slab (width, length, thickness, profile, contour),
  Calculation of volume and weight - Weighing no longer necessary,
- Archiving data for process optimization,
- Correlation with process parameters
- Optimization of optimal width setup.

5 IMAGE ACQUISITION

Image acquisition takes place by laser scanning. Depending on the slab/plate-width several units are installed across the width. Each unit consists of a line laser (i.e. one that projects a line, not just a dott) and a CCD-camera. The surface is scanned while the slab/plate is moving (Figure 2).

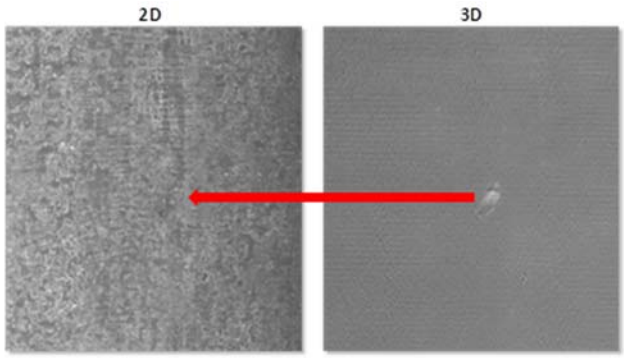

Figure 3: 3D shape of the surface and 2D gray value image of the surface

The evaluation of the camera images encompasses first the active triangulation to obtain the 3D shape of the surface and second the analysis of the local light intensity along the laser line to generate a 2D gray value image of the surface.

The resulting image is evaluated by the camera core and converted into a single height profile. The complete 3D data calculation is done inside the camera. This enables to acquire up to 32000 profiles per second. The camera is capable of delivering position data as well as additional features (e.g. intensity, line width) without sacrificing profile speed.

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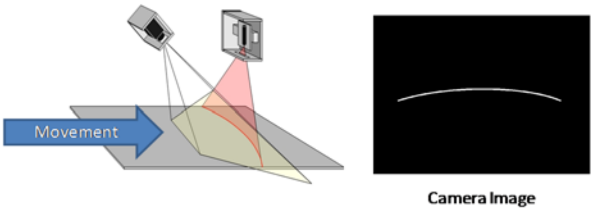

Figure 2: Image generation by light Intensity analysis and laser triangulation

Inspecting the surfaces of slabs used to be problematic with conventional systems. Because of the irregular surface textures, numerous defects could not be reliably distinguished on the basis of grey-scale images alone. In addition to the grey-scale image, the Surcon-developed X-3Dvision system now also provides a 3D topography of the surface. From the form of lines projected onto the slab surface, X-3Dvision generates a high-resolution image of the 3D surface contour. The system clearly distinguishes between greyscale differences and three-dimensional defects (Figure 3).
By measurement of the slab's top and bottom side, the entire thickness profile of the slab is captured. Combined with the feature for the edge contour measurement, integrated into the X-3Dvision system, the volume and also the weight of the slabs or heavy plate are calculated.
Typical defects of cast slabs are:

- Longitudinal cracks,
- Non-metallic inclusion,
- Tunnel furnace marks,
- Edge cracks,
- Transverse cracks,
- Star cracks,
- Scale defects,
- Mechanical marks,
- Mechanical scratches,
- Holes,
- Fire cracks.

Additional to the surface defects the following size defects are measured:

- Spread camber,
- Transversal depression,
- Edge camber

6 IMAGE ANALYSIS AND DEFECT CLASSIFICATION / SOFTWARE TOOLS

Due to the advanced 2 / 3D scanning unit, the synchronicity of 2D and 3D images is given immediately. The sequence of calculation steps to compute the surface quality information from raw images corresponds to those of industrial inspection systems, Figure 4.

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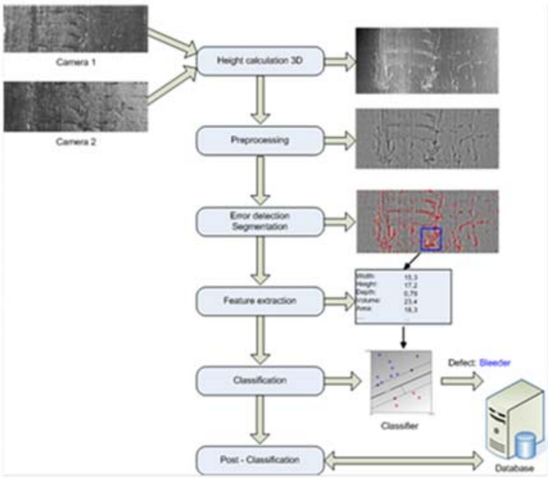

Figure 4: Flowchart of Data Evaluation

The core feature of the software is its capability of fully automatically detecting and classifying defects of any kind. The main benefits of the software are:

- easy-to-use tools for adapting the detection and classification features,
- fast training of the classifier involving little configuration effort,
- rules editors for defining optional classification rules,
- offline simulation tool for thorough testing of new classifiers on existing databases prior to going live.

The classified defect data are stored in a SQL server as inspection results. Arrays of hard discs of several terabytes storage capacity allow the production from several years to be tracked. The databases have a transparent structure, allowing external access. Through this structure it is possible to make individual adaptations and integrations to the database complementing the existing reports and evaluations.

The available RAM is large enough to store the complete video material taken from individual slabs or plates. This data can be used for comprehensive offline diagnostics and are also used for simulating and optimizing detection and classification performance. Consequently, going live and training of the system take much less time.

The system is easy to handle as the number of tools is reasonably small:

- “Inspector” is used to view, search and evaluate any stored data. (Figures 5, 6, 7).
- “Trainer” is the tool for setting up, managing and testing the classifier.
- The produced material can be displayed at any place by means of the “online view” module.
- Diagnostics by the system is fully supported by graphical HMIs.

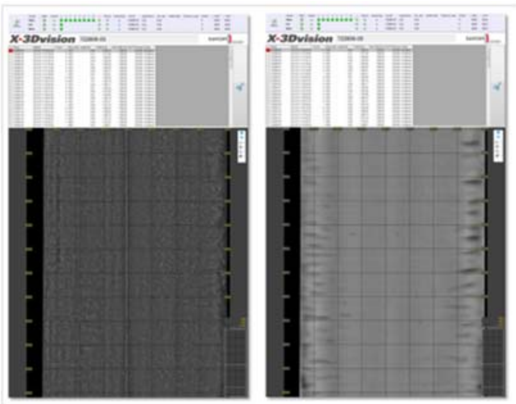

Figure 5: Inspector View

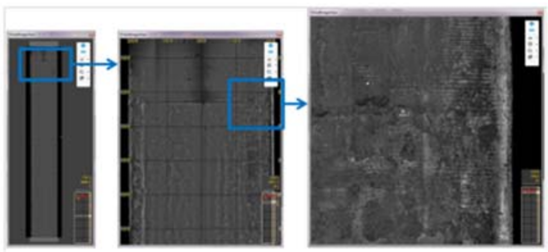

Figure 6: Slab Overview

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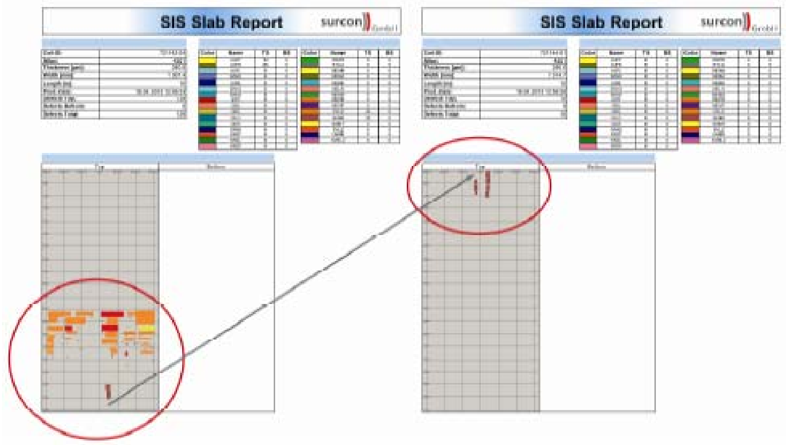

Figure 7: Slab Report

For the surface analyses there different possibilities:

- Easy and flexible selection of slabs and strips by material, dimensions, production period, etc.
- Various methods for defect data conversion in relation to slabs and strips:
  - Number of defects,
  - Total defect area,
  - Defect length area,
  - Affected strip lengths, periodic defects.

7 INDUSTRIAL INSTALLATION

X-3Dvision consists of a water cooled O-frame with several scan units arranged in pairs across the complete width of the slab, Figure 8.

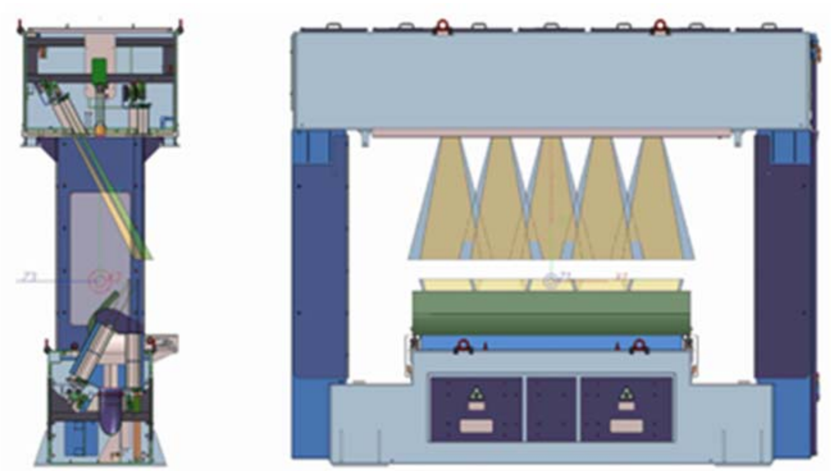

Figure 8: Mechanical design of the surface inspection unit at JSW, India

8 OPERATING RESULTS

Figures 9 to 12 are showing the measurement results for typical surface defects.

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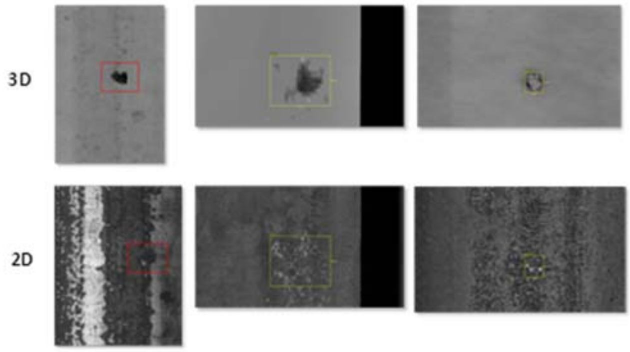

Figure 9: Mechanical indentations

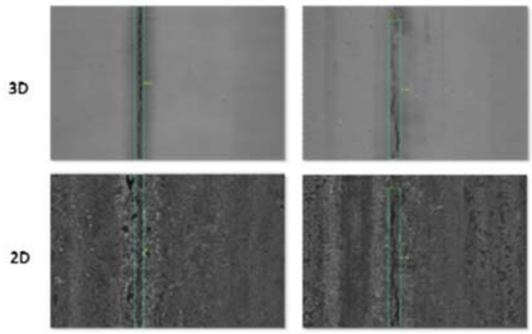

Figure 10: Longitudinal cracks

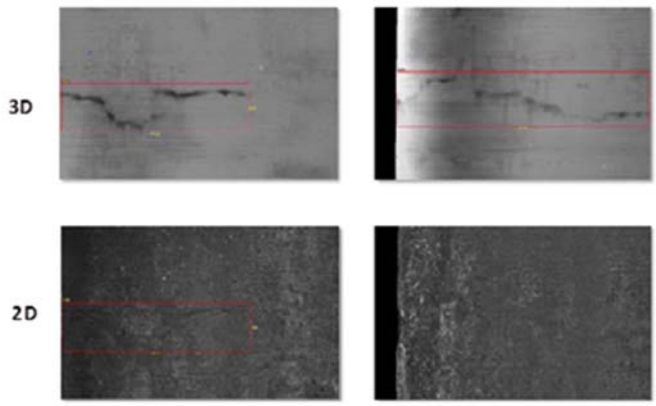

Figure 11: Transverse cracks

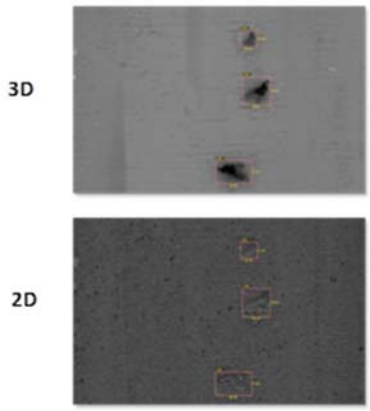

Figure 12: Bleeders

9 INTEGRATED QUALITY MANAGEMENT SYSTEM

The surface inspection system can be easily connected to the quality management system MEVInet-Q, Figure 13. It is a proven tool for performing comprehensive analyses of all process-relevant data.
MEVInet-Q collects and archives all information deriving from the process – both surface data and any process data provided by other measuring systems. By correlating surface data from the continuous casting, the hot strip and the cold strip, it is possible to identify defect sources which have their roots in upstream process stages and the effects of which may become visible only at a later stage.
For displaying the data, the “Data-Viewer” module is provided, via which production and quality experts may at any time access the archived data. The module displays individual measured values and data curves (longitudinal profiles, transverse profiles and defect profiles). The data displays can be freely configured and managed either centrally on a server or locally at one’s work place. If required, all displays can be published on the company’s intranet via the web browser. The MEVInet-QDS module is a rule based decision-support tool for quality management. Via MEVInet-QDS, rules can be defined that are automatically applied to every product in the production chain. These rules check quality on the basis of all available data. The operator may use the results from these rule based calculations as an aid in decision-making.

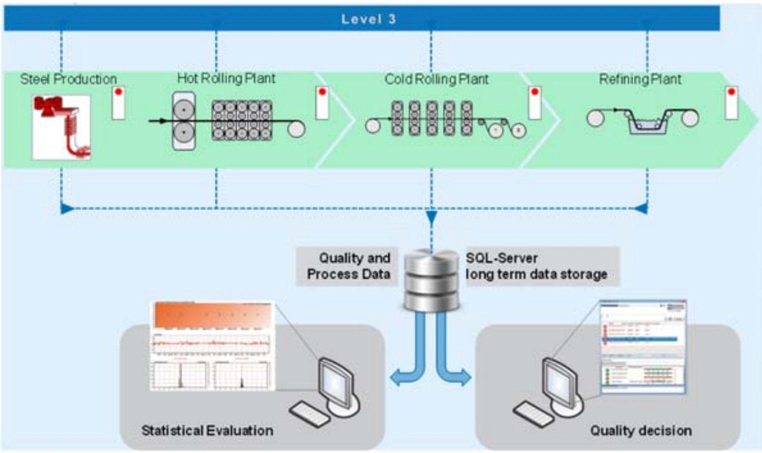

Figure 13: MEVInet-Q – Quality data processing for Integrated steel plants

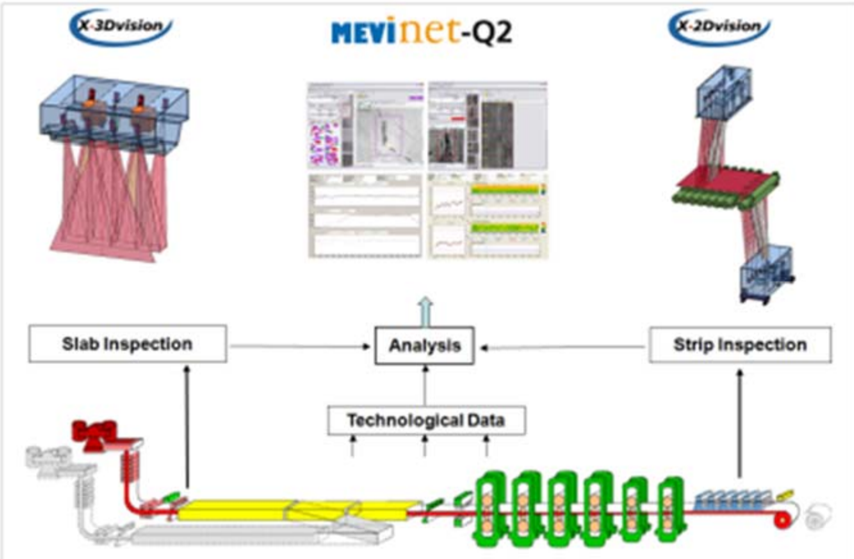

Figure 14: Surface data from the continuous casting and the hot strip mill

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