Slab Surface Defect Detection Techniques

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Introduction

There is a recognised need for an automated, on-line inspection technique to examine the surface and internal quality (e.g. cracking) of as-cast steel products.

There are a number of commercially available products on the market but this presentation will concentrate mainly on the techniques developed by the RFCS projects NDTCASTING and NDTSLAB.

A quick summary will also be given of some of the other techniques that are commercially available.

Introduction

Why Do We need On-line Crack Detection?

Traditional product inspection does not highlight issues for a significant time after casting. In the time between casting and inspection significant amount of product can be produced.

On-line crack detection provides feedback that the current cast product contains defects and steps can be taken to correct the problem in order to minimise any yield losses attributed to downgrading or scrapping a cast.

Final product inspection can ensure that no defective or 'out-of-tolerance' material is supplied to further processing and can be diverted for corrective actions.

Slab Surface Defect Detection Techniques

NDTCASTING

The aim of this project was to develop techniques for **non-contact** inspection of hot and cold slab surface.

Three main techniques were studied:

- Laser-EMAT (Tata Steel, UK) capable of detecting surface and internal defects
- EMAT-EMAT (BFI, Germany) capable of detecting surface defects
- Conoscopic Holography (Arcelor-Mittal, Spain) capable of detecting surface defects

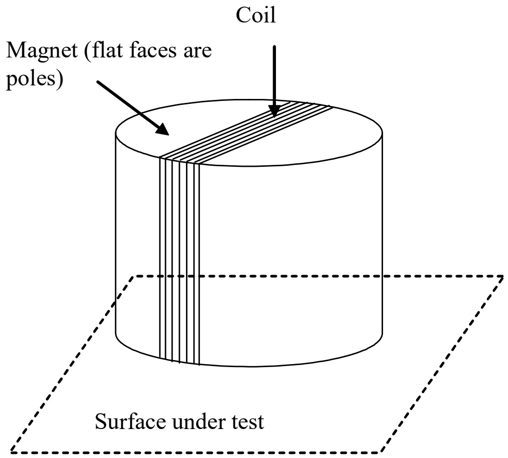
EMATs

What is an EMAT?

Electro**M**agnetic **A**coustic **T**ransducer

An EMAT is essentially a magnet with a coil wound around it.

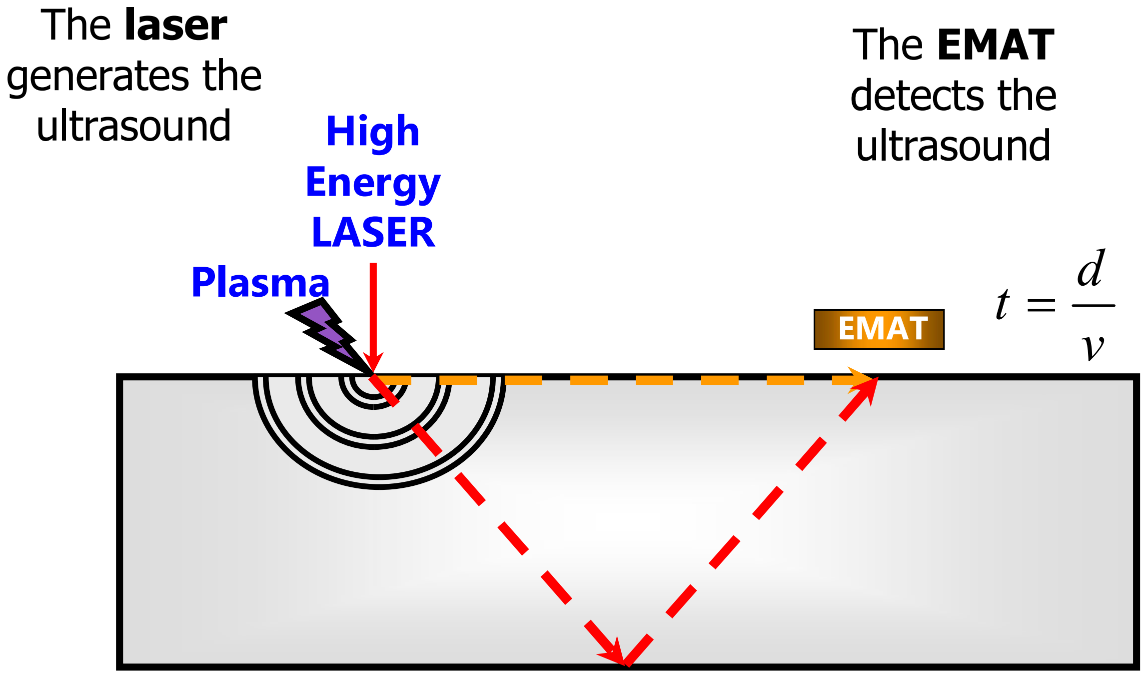
Movement in the form of vibration (or ultrasound) in the magnetic field induces a current in the coil which can be measured.



EMATs do not need any gel or water coupling as they are electromagnetically coupled. They do however need to be reasonably close to the surface.

Laser-EMAT

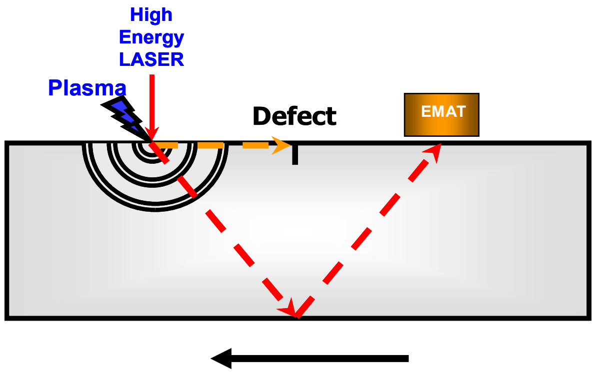
Principle of Laser-EMAT Ultrasonic Detection



- Each laser pulse generates ultrasonic waves in the steel.
- For each pulse a number of waves are received
- The time taken by the wave to reach the EMAT is know.
- Detection at any other time indicates a unknown interaction with the ultrasound.

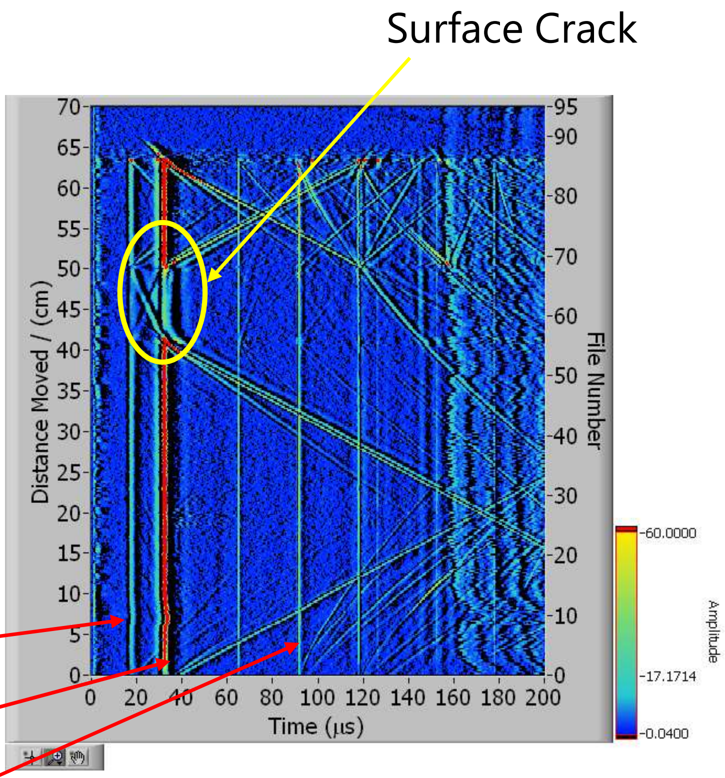
Laser-EMAT Technique

Detection of a Transverse Surface Defect



Billet Movement

- Transverse Defect blocks Surface and Rayleigh wave as it travels between the laser and the EMAT



Surface wave

Rayleigh Wave

First Reflection

B-scan

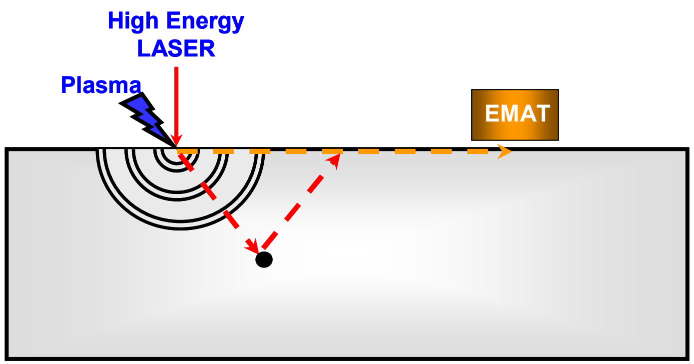
The B-Scan is a 3-dimensional graph with signal intensity plotted in the third dimension represented by a colour. Each horizontal line is the signal received from a single laser pulse.

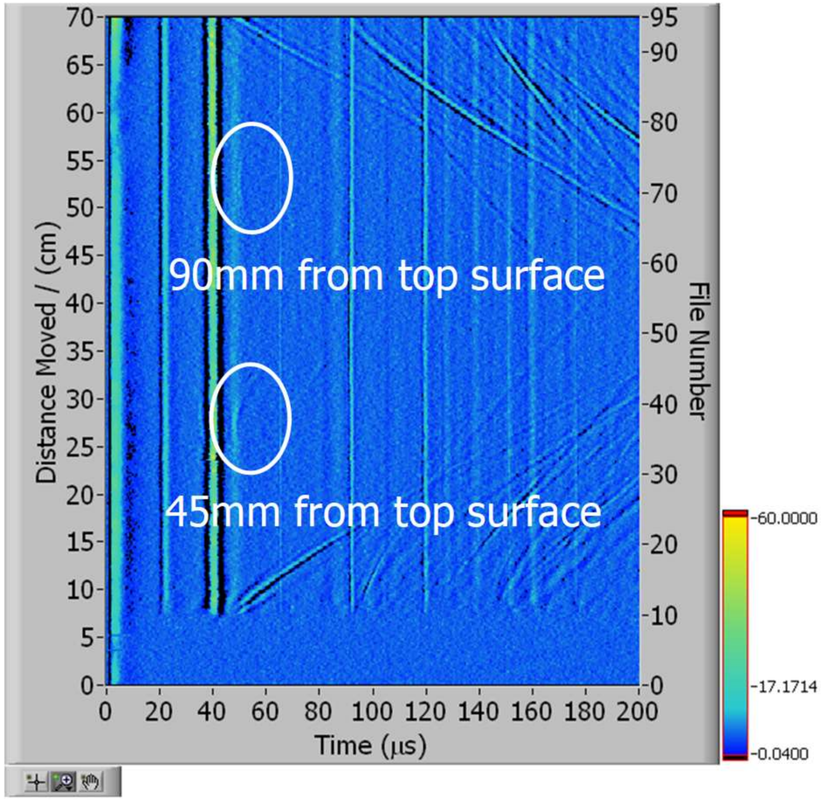
plot of the signals received for each pulse as the sample is moved The intensity of ultrasound received is indicated by colour.

Laser-EMAT Technique

Detection of an Internal Defect

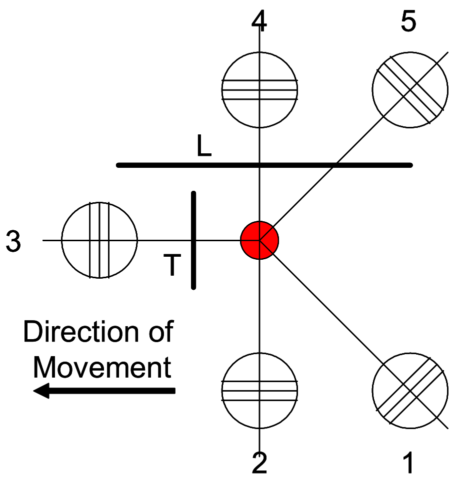
Internal Defect reflects the internal wave as it travels between the laser and the EMAT causing an extra reflection to be evident in the B-scan image but the surface wave arrives unaltered





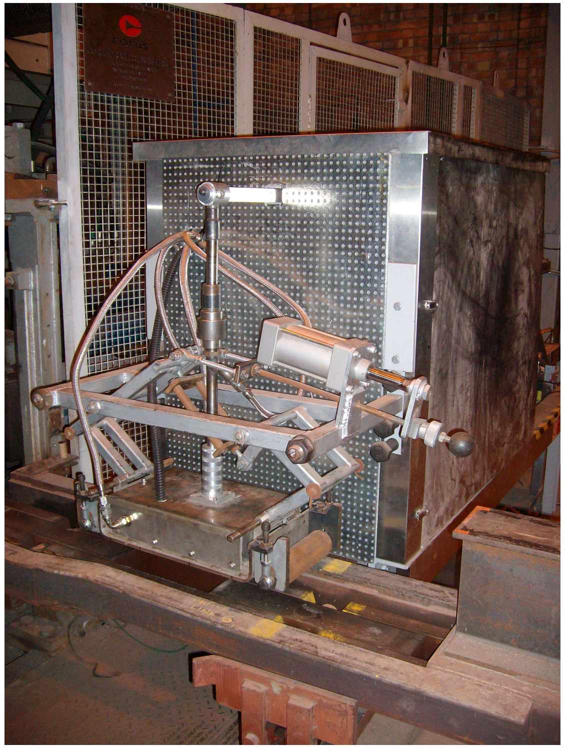
Laser-EMAT Technique

EMAT Array



EMATs detect waves travelling perpendicular to the coils.

In order to detect different orientations of defects an array was developed centred around a single laser.



Pilot Plant Installation

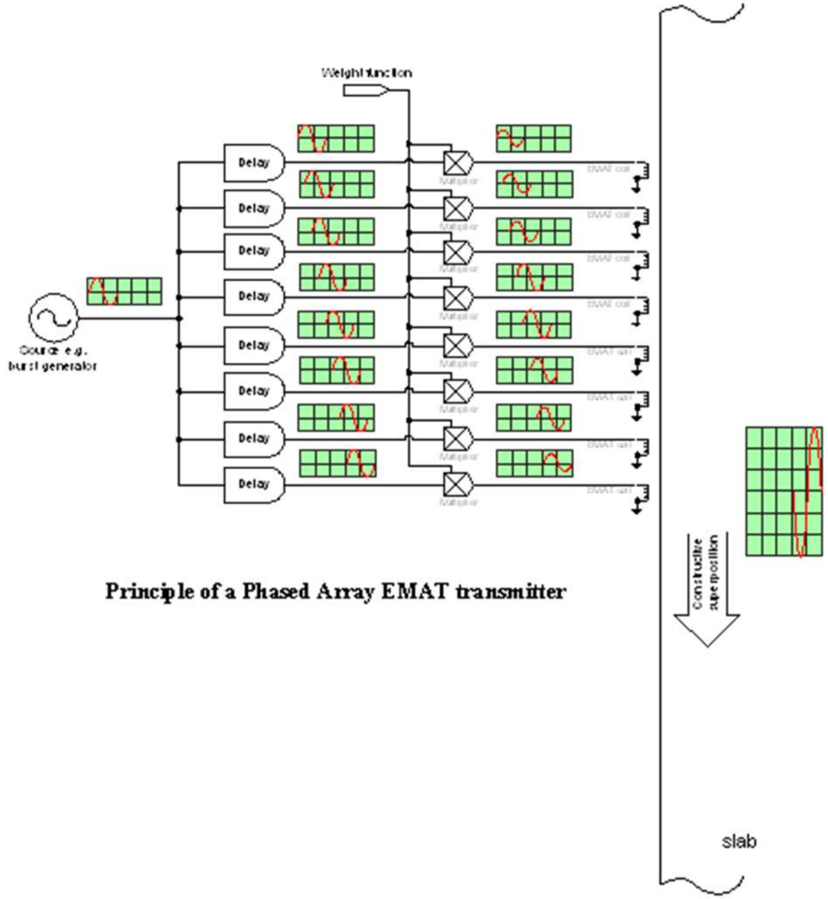
Laser-EMAT Technique

Summary

- A prototype Laser-EMAT system was developed.
- Good results were achieved in the Laboratory
- The system is capable of withstanding industrial conditions and has been installed on the Pilot Caster at Tata Steel.
- Hot trials were carried out with limited success with surface defects being detected in some samples above the Curie temperature (approx. 770oC)

EMAT-EMAT Technique

Principle of EMAT-EMAT Ultrasonic Detection



Principle of a Phased Array EMAT transmitter

The EMAT-EMAT system uses a phased array technique to generate and receive ultrasound.

A single input signal is fed through a number of amplifier circuits which are each delayed by a precise amount.

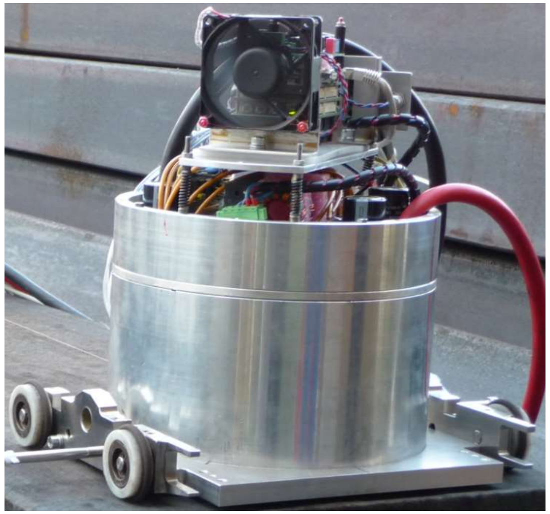
The top coil is pulsed first, and emits a pressure wave in the sample.

Each element is pulsed in sequence adding to the pressure wave. The process continues down the line until all the elements have been pulsed. The multiple waves add up to one single large wave front.

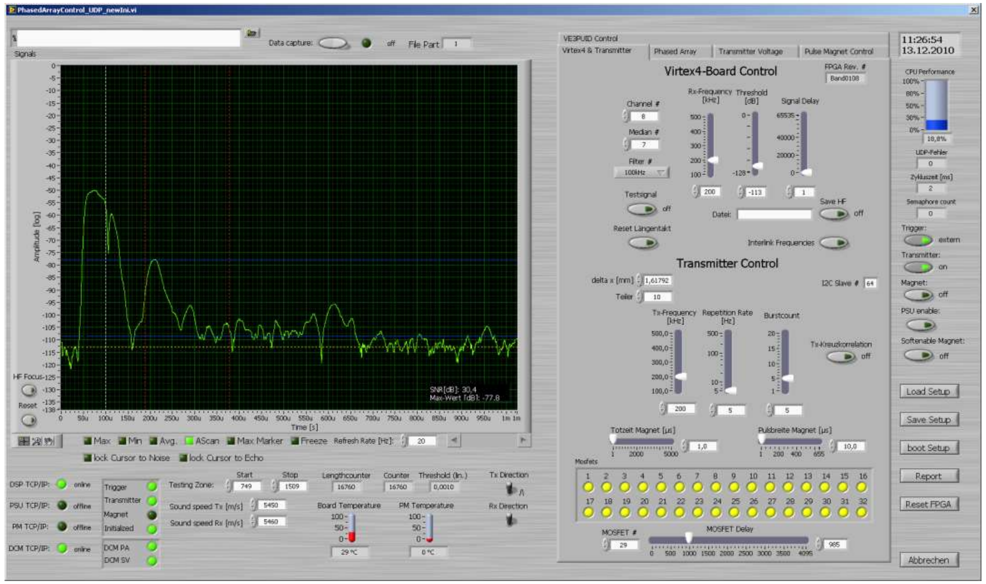
The phased array receiving system works using the same principle in reverse. An array of coils receive a signal which is added together.

EMAT-EMAT Technique

A prototype system was built using Surface waves (Rayleigh waves) to find surface and subsurface defects on steel products. The system was proven on as-cast slab in the slab yard even if the surface is rough, contains oscillation marks and scale oxide.



EMAT-EMAT Phased Array probe
for Rayleigh waves testing



EMAT-EMAT Technique

Further development of the EMAT-EMAT technique - NDTSLAB

A follow up project to NDTCASTING was a collaborative project between BFI, Salzgitter, Materials Processing Institute and TATA Steel to further develop the industrial application of the EMAT-EMAT technique.

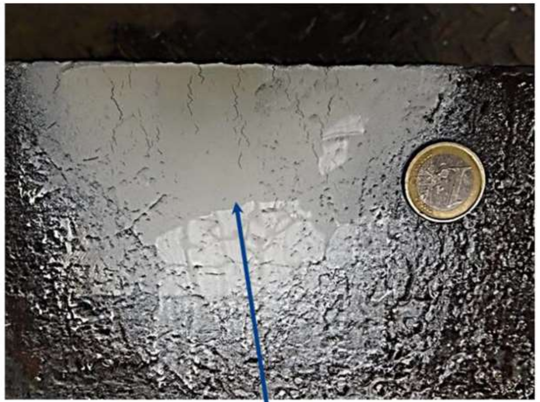
A heat resistant Phased-Array EMAT optimized to the application was developed with improved range and better suited for the detection of cracks on the slab edge.

A mounting arrangement which allows the movement of the probe on a track across the slab surface was built.
The mechanism was controlled by a programmable logic controller. The probe position and angle of the sound are transferred to the ultrasonic testing system.

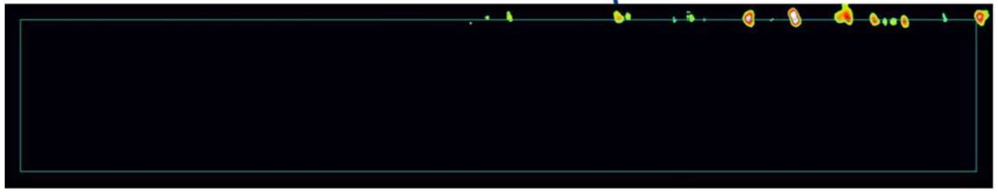
EMAT-EMAT Technique

Industrial trials were carried out on whole slabs with different surface and temperatures

Numerous crack indications were identified along the edge of the slab. Cracks were found at all these locations using the magnetic particle technique.



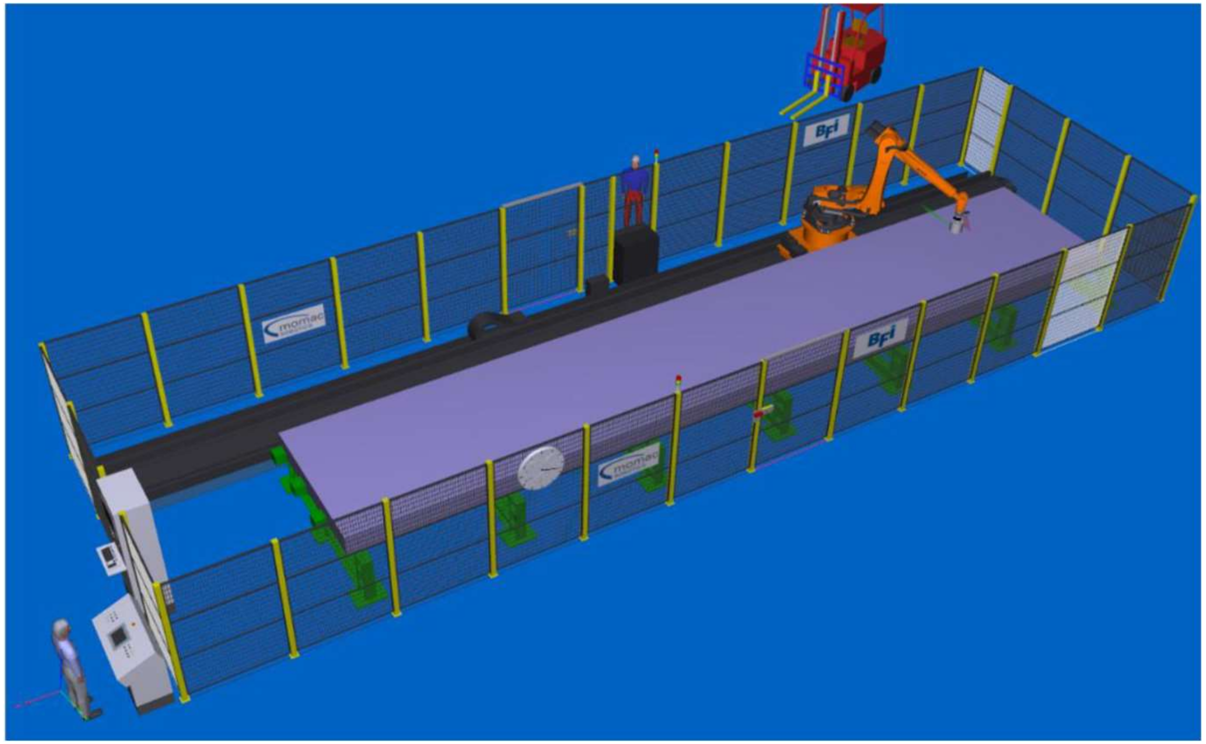
The EMAT system has been demonstrated to be capable of finding defects in as cast steel slabs that cannot be found visually with grinding or scarfing of the surface.



With tuning of the signal to noise ratio in the surface scan image defects as small as 5 mm^2 can be detected. Defects smaller than this are not readily detected by the EMAT system

EMAT-EMAT Technique

Proposed Future Development



For future application it was suggested that robotic arm could be used to carry out the inspection

Conoscopic Holography

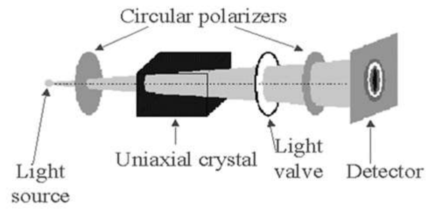
Principle of Conoscopic Holography

Conoscopic Holography is a form of incoherent light interferometry.

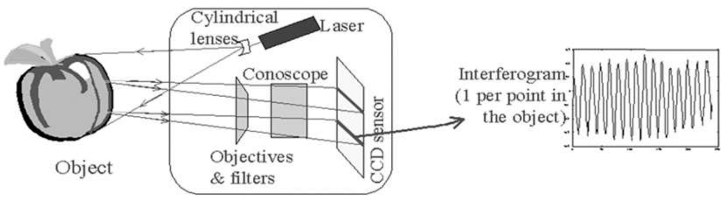
Based on the interference that occurs between ordinary and extraordinary rays into which polarised monochromatic light is divided when crossing a uniaxial crystal. This can be used to accurately measure the distance to a point illuminated by a laser.

This system uses a fringe pattern technique to create a 3D ‘map’ of a surface which can indicate visible surface defects

Usable at cold and hot slabs



Set-up of a point conoscopic sensor

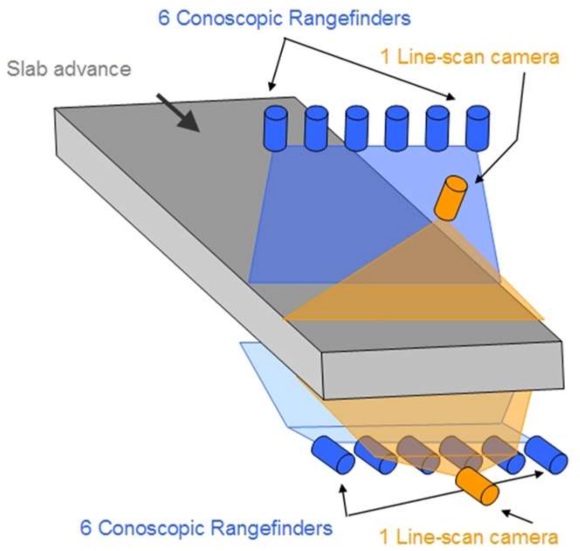


Set-up of a conoscopic long-stand-off range-finder (conoline)

Conoscopic Holography

The Conoscope used in the NDTCASTING project installed at Arcelor-Mittal, Spain was a commercially available system.

- Complete width of both faces of slabs is inspected.
- Temperature of slabs (600 – 900 ºC) does not affect the system as it is protected in a forced-refrigeration chamber completely isolated.
- All slab formats are inspected, from wide 500 to 1600 mm
- Operation is fully automated



Conoscopic Holography

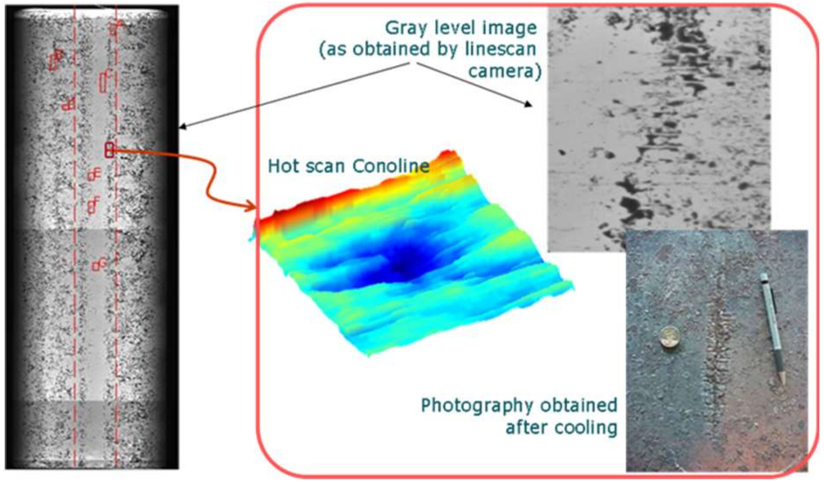
Initially the system was used to detect longitudinal cracks in the as cast surface.

During the project the automated algorithms for defect detection were improved. Additional defects such as very thin and zigzag cracks can now be reliably detected.

Over detection was also decreased.

The use of this online system has allowed an increase in the ratio of hot charging.

Information from the system facilitates an early detection of casting problems, thus allowing a faster response.



Other Techniques

Eddy Current Crack Detection

- Eddy Current Crack Detection has been proven to be capable of detecting surface flaws in semi finished products at temperatures up to 1150ºC. It requires that the transducer heads be held within a few millimetres of the surface of the product.
- Eddy current systems are noted to be capable of detecting cracks just below the surface that are not always visible from the surface including closed up cracks.
- The RFCS project - Multiplexed eddy-current arrays for the detection of corner cracks on as-cast products in the inspection yard and at the exit of continuous casting. Carried out by ArcelorMittal, Dillinger, Sidenor and ThyssenKrupp Stahl.
- The trials had limited success on Slab and good results with billet.

Other Techniques

Infra Red Inspection

A number of systems such as the "IRUS" system or "Therm O Matic" are in commercial use.

Thermal imaging technology is used to view a billet surface which following inductive heating. The edges of the cracks emit more heat following the surface heating. This is picked up by the thermal camera.

Other Techniques

Line projection systems

These systems project a line, usually laser generated, onto the surface of a slab.

Deviations in the line from straight are interpreted to give a contour across the surface. Successive contours may be put together to form a surface map from which the presence of cracks may be detected.

Thank you for your attention.