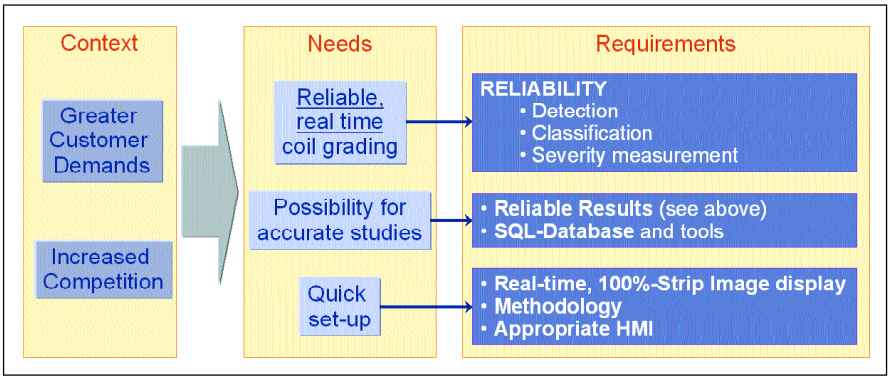
Dynamic surface inspection in hot-strip mills

The VAI SIAS automatic inspection system is capable of detecting individual, repeating and scale-type surface defects on hot strip and of classifying them in real-time to provide valuable surface quality information. Two installations are already in production use, with two more on order.



● **Figure 1** ***General specification of major surface inspection requirements***

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In December 2003, VAI SIAS received acceptance for its first hot-rolling mill automatic surface inspection (ASI) system from Sollac Atlantique, Dunkerque Works, part of the Arcelor group. This represents a major breakthrough for quality management at this stage of strip production, as the system can be fully integrated into the decision-making process of the production department.

Project background

At the time of this investment Arcelor (then Usinor) had already acquired significant experience in the application of ASI to the production of steel strip as all of the group's hot-dip galvanising lines for automobile products are equipped with ASI systems from VAI SIAS (formally known as MATRA). The systems are not simple gauges that generate a map of each coil where defects are represented: the measurements, which are provided in real time, are precise and reliable, enabling decisions to be made during processing to prevent or minimise defects, thus enabling a dramatic reduction (>90% for some products) in the percentage of production sent through the long and costly visual re-inspection process. More importantly, this result is achieved without the additional intervention of a system expert or any other additional procedure. Now the quality inspector alone is capable of quickly making a decision on delivery of a coil that has just been produced. A general specification for major surface inspection requirements is shown in *Figure 1*.

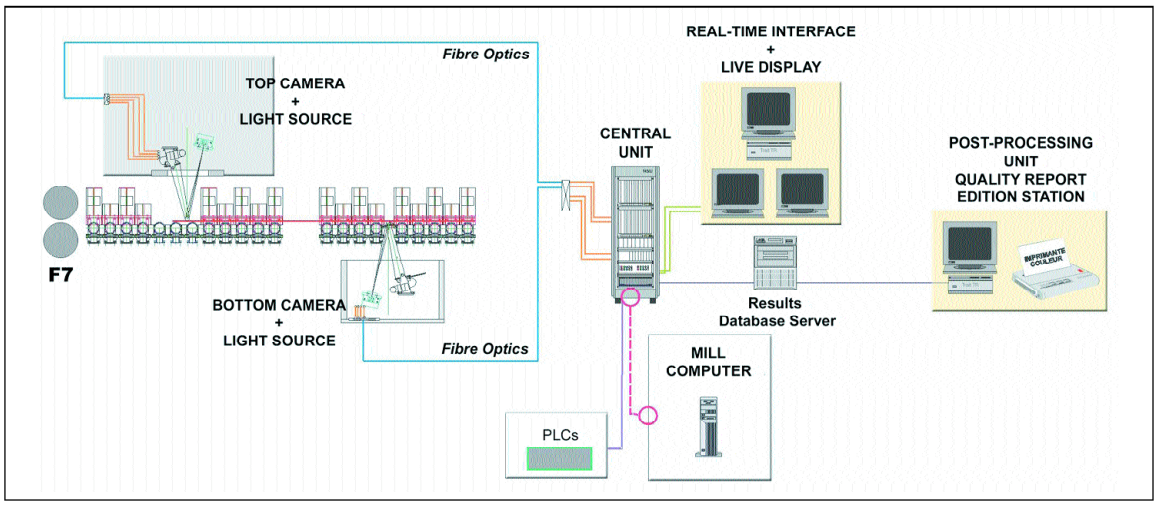
The benefits of earlier, upstream detection of surface defects with the same efficiency are as follows:

- Avoids 'defect crises' by early identification of the defect origin (for example, roll change)
- Defective product is immediately removed from the production stream
- Reduction of losses due to traditional quality control practices (wrap, re-inspection)
- Faster feed-back to upstream production units (caster)

A common specification was written by end-users and ASI experts to address the requirements of Arcelor's hot-strip mills in need of a surface control solution. The Dunkerque hot-rolling mill was selected as the pilot site and, following a thorough benchmark evaluation of two suppliers, VAI SIAS was selected as the supplier that could meet all of Arcelor's requirements.

Key facts at Arcelor Dunkerque HSM are:

- 5.3Mt maximum capacity
- Material produced:
  - Low carbon steels
  - Silicon steels
  - High strength steels
  - High carbon steels
- Maximum speed: 1,000m/min
- Minimum inter-coil time: 7s
- Strip width: 600–1,940mm
- Strip thickness: 1.2–16mm
- Strip length: 100–2,000m



● **Figure 2** ***Arcelor Dunkerque HSM: Location of equipment and global system architecture***

System specification and operation

The installed system has the following characteristics:

- Top and bottom side inspection
- Halogen lighting (6kW each)
- Two linear cameras per side
- 0.5mm cross-web resolution, 1mm down-web resolution

The bottom-side acquisition assembly was installed in an existing pit at the end of the run-out table, and top-side acquisition was positioned right after the finishing mill (see *Figures 2 & 3*).

The principle of the system operation is as follows:

- Acquisition of the image by line-scan CCD cameras
- Processing of the image, detection of flaws and segmentation into 'objects of interest'
- Software classification to sort these objects into defects (shell, slivers, scale and so on), or irrelevant objects, which are classified as pseudo-defects and eliminated from the report
- Severity evaluation
- Real-time result display

The definition of this configuration was the result of a systemic approach by Arcelor, which had a clear idea of the objectives the system was required to fulfill, and by VAI SIAS, which had acquired the necessary know-how and expertise over more than 10 years' activity in image processing for industrial applications.

The four system objectives

The standard industrial performance indicators (for example, availability rate) or the traditional performance objectives (for example, detection and classification rates), often requested from such a system are applicable in this ASI application. In addition, there are four rules that should prevail:

Zero defects missed One of the main concerns of the quality manager at a hot-strip mill is to prevent any defective material from being delivered to customers. When the surface inspection system investment was decided for Dunkerque, it was absolutely essential that none of the defects that may

● **Figure 3** ***Bottom side inspection equipment***

be judged as critical for final applications (for example, automobile exposed products), should be missed by the chosen system. In the benchmarking trials it was demonstrated that the VAI SIAS system could reliably detect and discriminate even the smoothest occurrences of secondary scale ('salt and pepper'). This is clearly a benefit of the use of linear cameras, with the lighting control techniques and streamlined image processing methods that they allow.

No paranoia The risk associated with a system meant to report the slightest flaw is that it keeps reporting 'defects' that turn out to be non-defects or ones within acceptable tolerances. This is perhaps the most devastating effect that a surface inspection system may produce as it will keep alarming quality control personnel for no reason and the controllers will then start questioning its accuracy and use. What is the purpose of a so-called 'automatic' system if every piece of information needs to be double-checked? In the end, given the huge quantity of data generated, at best the system would require at least one full-time employee to perform these checks, thus greatly compromising the return on investment. At worst, those in charge of using the system will determine that it cannot be trusted and will stop using it, hence the investment will have become a net loss. Therefore, to avoid this situation, it is necessary that two conditions be fulfilled:

First, all the necessary measures must be taken so that the system only sees objects that are actually impairing quality. It is necessary to make the strip – as well as the space between the strip and the sensor – as free as possible from water drops, dust, steam, dirt and so on, or any environmental intervention that can either prevent or unnecessarily trigger detection. At Dunkerque, these measures included putting the water cooling on the run-out table 'on hold' during strip presence/inspection and the installation of complimentary air blowers and water flushes.

Second, for those objects that remain, the system's classification must be extremely reliable. Here, VAI SIAS' experience from the aerospace and defence industries proved critical in that the extremely elaborate methods developed for such applications as the military 'fire and forget' principle were adapted and successfully applied to the inspection of steel strip surface defects.

Implement new coil allocation standards Assuming the first two objectives are reached, critical adaptation work needs to be undertaken. Indeed, once the system has been commissioned, due to the accuracy of defect detection, the quality team is initially confronted by a huge quantity of data, as the number of surface defects reported reaches a level that is in no way comparable to previous standards. In these conditions, if the former quality standards are maintained, the risk exists that none of the coils produced would pass the quality control criteria.

A surface inspection system does not create defects; it only reports a constant, repeatable measurement that is in essence more complete than any human control. Thus, the user of ASI must switch from an old quality control method based on partial, visual inspection to a new reference where the system's results are integrated. Arcelor was prepared for this task as it had already gone through the same process at the early stage of ASI implementation on its process lines.

VAI SIAS' specific severity measurement method allows a gradation in the appreciation of a given metallurgical defect, based on other criteria such as size or location on the coil. However, implementation at the hot-strip mill took the exercise to a new level as, unlike on process lines, on-line visual control was not possible to compare system results with experience. During system commissioning, quality inspectors sometimes were required to take the coil to the inspection line to see what the defect actually looked like. Eventually, this step proved of particular interest for the quality department as, for the first time, they had instant access to surface quality information for the whole strip.

End commissioning – start working The final indirect, yet equally important objective that VAI SIAS had to guarantee, was to actually make the system useful in a given period of time. There are several stories of ASI implementation projects, where the system has been under continuous commissioning for months or even years without reaching the performance targets. In these stories the system, which had initially been purchased to relieve the plant from one of the tasks that adds no value to the final product (quality control) has, unfortunately, become the source of a new concern for the production team.

At Dunkerque this step was achieved by use of a thorough methodology throughout the commissioning process, backed by exclusive VAI SIAS tools such as the live image display module, Dacôdac commissioning software, and the availability of numerous follow-up indicators to take into account the conditions of inspection in the global evaluation of the system's performance.

Achievements and future perspectives

The system has now received performance acceptance from a very satisfied customer:

- The performance of the system exceeds 96% in terms of detection for all defects (repeating, area-type and individual). The system thus fulfills its role of warning operators of abnormal production conditions. Defects caused by the mill, such as a roll mark, that would affect a whole

production campaign are now only a memory
- There has been a 50% reduction in material losses caused by tail-end inspection (tail-end inspections remain necessary for defects generated at the down-coiler)
- The system availability rate over a six-months period is judged excellent
- Classification results were accepted at the end of 2003 and are now so reliable that automatic grading of the coil is possible, based on the system results and the client specifications

Currently most production surface quality decisions are made based only on the information provided by the system. This proportion is expected to grow as the knowledge of a given defect's evolution through the whole downstream process increases. This will eventually make more precise and accurate diagnostics possible regarding what is the best allocation to make for a coil with a given combination of defects. The ongoing studies that will lead to this increase in defect knowledge will be made easier by the fact that four of the mill's most important customers (the pickling and packaging steel lines of Mardyck, and the two hot-dip galvanising lines of Montataire and Mardyck) are also equipped with VAI SIAS surface inspection equipment – and can thus also provide extremely reliable surface-related data which can be traced back to source.

Conclusions

The project is considered by all parties to be a total success, so much so that a second system using the new XLine version will be installed in Sérémange Works, Eastern France. Also, two more systems have been ordered or supplied. One at NLMK's Hot Strip Mill 2000 in Russia was undergoing the final stages of commissioning at the time of publication of this article, an outstandingly rapid installation; while the second will be delivered later in 2004 to the Angang group, PR of China. VAI SIAS has thus, thanks to the Dunkerque project, reached the status of reliable supplier of industrial solutions for the highly demanding requirements of hot-strip surface inspection; an industry which, given the outstanding benefits it may bring to customers in terms of quality management, is promised a bright future.

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