

Real-time inspection of steel strip

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I. INTRODUCTION

Quality control of production has always been a necessity in stainless steel mills. The users of stainless steel set ever-increasing requirements on product quality. Many material properties can still only be measured in laboratory but more and more measurements are now made on-line during the production. Especially surface defects have to be detected on-line with a surface inspection system because of their random appearance.

The purpose of a surface inspection system is to detect and classify surface defects that impair product quality with regard to the requirements set by the user. The requirements mostly deal with the suitability of the product to the intended use of it. In the worst case the defects may make the product functionally deficient or even unusable. Critical defects are also those which cause production disturbances.

Automatic inspection systems for metal surfaces have been available for some time, but not until recently, the development of electronics and information technology have made the actual image analysis applications possible [1] [2]. Older systems utilised various technologies for detection. At best their sensitivity was good, but an obvious shortcoming was that they classified the defects only on the basis of a few grey level values, e.g. into holes, dark spots and light spots. No other information in addition to defect size was available. The current systems use CCD-sensors to produce grey scale images of the defects. These images provide new opportunities for defect classification [3].

II. THE NEED FOR SURFACE INSPECTION IN METAL INDUSTRIES

There are many types of metal surface imperfections. In general, large defects are more critical than small ones, but stainless steel users may also be concerned

about defects whose diameter is only tenths of a millimetre. There are two main categories of reasons for steel mills to strive for defect free material: internal and external ones. When making a continuous strip product at a high speed, the imperfections in the strip quality often create problems in production. External requirements come from the users of the material. Out-of-quality end products may cause returns or even result in losing a customer.

Worst problems that material defects may cause in a steel mill are coil breaks. With the help of surface inspection system coils with critical defects, that can cause coil breaks in the rolling mill, can be blocked. Such critical defects are for example edge cracks, holes and heavy slivers.

Steel producers want to know emergence of such defects that may prevent running the process smoothly and to make sure that the product quality meets the customer requirements. The causes of different defects should be located and removed as soon as possible. If defects are present they also should be recorded for different types of statistical quality reports. Without a surface inspection system, surface defect identification and root cause tracing can easily take a long time. During this delay the problem may repeat causing even more downgraded production.

III. BENEFITS OF AUTOMATIC SURFACE INSPECTION COMPARED TO VISUAL INSPECTION

Traditionally, many annealing and pickling lines have visual inspectors to do the surface inspection. Compared to this method, automatic surface inspection offers several benefits. With an automatic system it is possible to be sure that 100% of the material will be inspected. When a certain defect type starts occurring it will be noted immediately. Also, consistent inspection result is achieved. Better reporting is possible since pictures of every defect can be saved. Flexible reports are available when the defect data is saved in a SQL database. For modern high-speed production lines an automatic system is the only possibility because the speed is too high for visual inspectors.

As a summary, important facts provided by a web inspection system are, e.g.:

- Providing consistent 100% surface quality inspection
- Reducing costly reject production and customer claims
- Improving real-time process control
- Identifying preventive maintenance
- Facilitating quality grading of products
- Defect statistics for quality follow-up

IV. STAINLESS STEEL DEFECT TYPES AND THEIR CLASSIFICATION

Most of the defects are optical surface flaws, which are detectable also by a human eye. For this reason, surface inspection systems also use optical principles for detection. Accordingly, as defective are regarded those areas of steel which deviate enough from the average steel.

The number of surface defect types in stainless steel is large. Defects can be divided into 30 – 40 different classes on an annealing and pickling line. Also the naming of similar defects may differ from plant to plant. But the basic idea is that with flawless steel the system produces a certain signal level. If the signal gets weaker, a detection of a dark defect is the result. If the signal becomes stronger the system indicates a light defect. The final classification depends, of course, also on the spatial distribution of the varying signals.

In the following the most common defect types are studied in more detail.

Holes are discontinuities in the material which extend right through from bottom to top surface. Holes occur as a result of the material tearing [4].

Shells are irregular, flaky overlapping material permeated with non-metallic inclusions. The overlapping material has an irregular perimeter and is separated by non-metallic or oxidic inclusions, or scale, from the base material [4].

Inclusions (Fig. 1) are narrow longitudinal marks that run in the direction of rolling. They can be lighter or darker than the steel surface [4].

Blowholes are internal discontinuities in the material [4].

Scales can be present in surface due inadequate descaling or pickling.

Scratches (Fig. 2a and 2b) can be caused in hot rolling mill, annealing and pickling line, cold rolling mill or skin pass mill. For process development purposes it is important that the system classifies different scratch types correctly.

Pimples are periodically occurring raised points on the strip surface. They can be caused by cold rolling or temper rolling as a result of depressions on a work roll [4]. Some of the pimples are extremely difficult to detect because of the small size and low contrast of the defect. On the other hand, whenever the pimples occur they can be found in the entire coil at certain intervals. Visual inspectors often check the pimples by slowing down the line and touching the surface by

hand. ABB has developed a sophisticated SW algorithm to detect pimples. It is based on the repeating nature of the pimples.

Roll imprints are indentations or depressions on the strip caused by foreign bodies on the work rolls.

In addition to these most common defect types several defect types can be found.

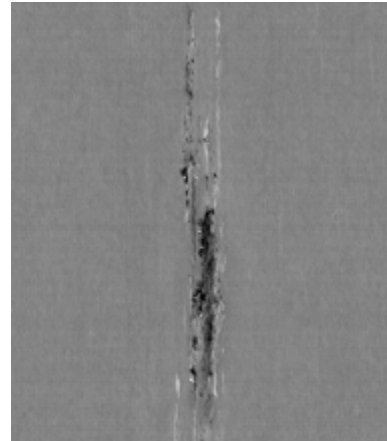


Figure 1. Slag inclusion



Figure 2 a. Scratch from cold rolling mill

It is necessary for the metal surface inspection system to classify defects correctly according to the causes of defects. Also, the severity of the defect should be identified, for example, to find out if product fits the intended use. ABB is using neural network method to classify the defects.

The starting point for classification is the image captured by the camera. The first step after the image capture is segmentation i.e. separation of the defective area from normal material. Traditionally defect

segmentation has been very rough. The advanced segmentation method developed by ABB follows the borders of the defect very accurately. This improves the classification result remarkably compared to conventional methods.

After segmentation different features are calculated from the image. These features can be for example length, width, area, borderline regularity, convexity and grayscale level distribution. Typically a couple of dozen features is used, but there is no limit to the number of features used in the classification. Adding more features after a certain level does not contribute classification of the defects. When the features are calculated a feature vector can be put together. Defects with about similar feature vectors are classified in the same class by the neural network.

The neural network has to be taught. The best way of doing that is that the operators gather defect images and give the correct class to them. Different computer based tools are available for making this stage easier for the user.

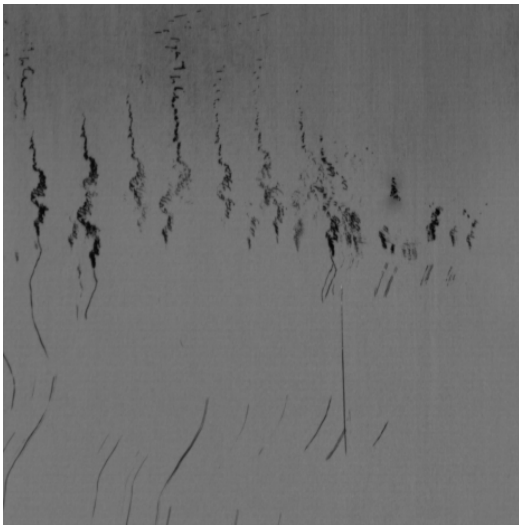


Figure 2.b. Scratches from annealing and pickling line

V. SUBTLE DEFECT DETECTION

Due to ever increasing requirements of metal users, more and more subtle defects have to be detected. If the contrast of a defect is clear and the size is big enough, the conventional systems have no major difficulties to find them. These systems use simple but fast averaging and thresholding techniques. They can even make a simple classification (e.g. identifying a hole) in real time to make a decision, for example,

whether a digital output should be switched on to start a process control signal. More time consuming computations for less critical purposes, e.g. precise classification can be done with a time delay. But when the defect grey scale values are of the same magnitude with the normal variation of the product, the detection task becomes much more difficult. Then the defect cannot be detected by simple methods. There are different techniques that can find many of these subtle defects, but their deficiency is that they are computing intensive and require a lot of processing time with conventional computers.

A typical camera in a surface inspection produces analogue grey level signals of about 20 million pixels (picture elements) in a second. Depending on the required spatial resolution, several cameras per each metre in CD may be necessary. It is obvious that each camera needs its own data processor. However, the data flow is so fast that even a fast PC is not fast enough if sophisticated image analysis has to be performed. Therefore only a hardware solution is possible.

A modern digital camera that meets these tough requirements is realised with high capacity PLDs (programmable logic devices). These devices contain tens of thousands of hardware logic gates which can be "wired" by software program to perform desired algorithms. A superior feature of this solution is that it can attain practically any number of complicated parallelisms with the full speed of hardware, whereas PCs make their calculations mostly only in a serial mode and can not come even close to the speed of PLDs. An advantage of PLDs over hardwired electronics is that PLD's configuration can be changed by a new program any time. This provides the flexibility that is sometimes needed and also makes the system upgrades easy.

Low contrast inclusions and scratches are examples of subtle defects. Their contrast is often so weak that the traditional methods cannot even detect them. Therefore, special algorithms are needed. These algorithms utilise the specific features of inclusions and scratches to enhance the signal and finally detect it. The most difficult problem here is the detection in real time. For many of these subtle defects the above-described PLD system is the only solution available today.

VI. ARCHITECTURE OF A MODERN SURFACE INSPECTION SYSTEM

Figure 3 shows ABB's surface inspection system. It consists of camera beams, light source beams, defect information processing electronics and operator station, classifier and database PCs. Standard local area networks are used for distributing information between operator and office stations. The camera beams con-

tain several cameras so that all the strip width in cross direction is covered and resolution requirement is met on both sides of the strip. Defect information is sent to operator station via optical link to prevent electromagnetic interference. The operator station is a standard PC and combines the information coming from different cameras to form various user displays and reports. The classifier PC classifies the defects and the defect data is saved in SQL database to facilitate flexible reporting. The light source beam is needed to achieve sufficiently strong and even illumination on the surface to be inspected. The type of the light source varies according to the specific needs of the metal grade. E.g. wide spectrum tungsten, fluorescent tubes or fiber optic light sources are typically used. The need for ripple-free illumination calls for special arrangements in lamp power supply units.

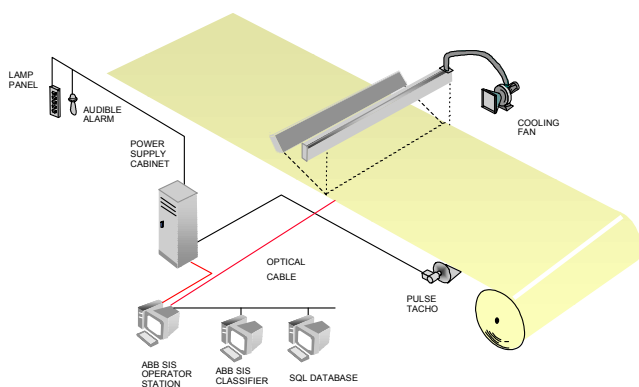


Figure 3. Surface inspection system

Line scan cameras have been widely used because the second dimension is achieved with the help of strip movement. Their benefits, when comparing to matrix cameras, are that they have been designed for demanding industrial applications with high quality requirements what comes to sensitivity, signal/noise ratio, and pixel to pixel evenness. Line scan cameras are also available with 2048 and even 4096 pixels that makes it possible to achieve high CD resolution. Also, it is easier to realise a strong and even illumination to the surface area to be inspected for a line scan camera.

Some system integrators use general-purpose off-the-shelf cameras, image processing boards and separate data processing computers for each camera. This adds the complexity of hardware, which is emphasised when camera density has to be high e.g. for detection of the smallest defects. It also makes it difficult to realise the fast real-time algorithms needed for subtle defect detection, as explained above.

VII. SINGLE SENSOR CAMERA AND SIGNAL PROCESSING

The solution developed for the ABB SIS is an intelligent multifunction line scan camera. The considerations presented in the previous chapter have among other things contributed to the decision to rely on the line scan principle. The sensor itself consists of two main parts (Fig. 4): CCD-element unit and signal processing unit containing electronic modules. The camera signal processing is distributed to different electronic modules, which are installed on the same motherboard. The functions are divided between these modules and processing done in parallel to get as high throughput as possible.

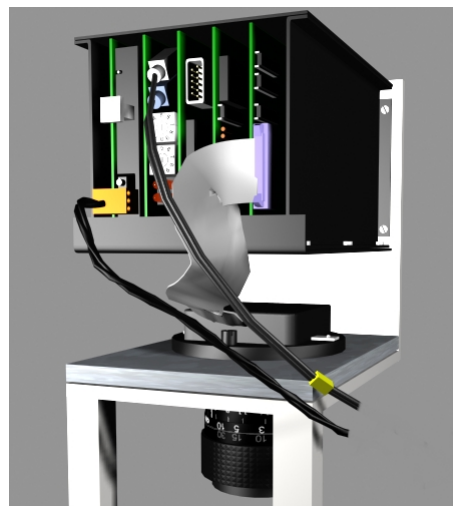


Figure 4. Modular single sensor camera

The object (the metal surface) is imaged on the CCD chip by a standard lens. The signal-processing unit makes 12-bit A/D-conversion and subsequent processing of CCD output signal. The camera is based on modern digital signal processing and processor technology utilising DSPs and PLDs. An advantage of this special camera is that in it a desired number of truly parallel computations and algorithms can be run at a high speed.

VIII. OPERATOR'S DISPLAYS

The operator station displays consist of multitude of video pages, e.g. defect maps, trends, profiles, repeating defect and formation developed for Windows NT operating system. Figure 5 shows one example page of the information presented to the machine operators.

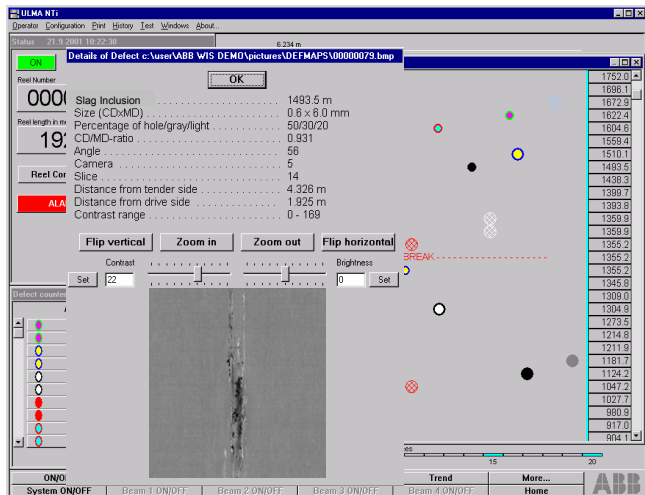


Figure 5. An operator's display

IX. CONCLUSIONS

A new era for metal surface inspection has started when the electronic imaging systems have gained such a status that it has become possible to take high resolution images. The defect images are saved in computer memory and they can be used to aid the daily operations like production line diagnostic. It is also very important for the system to classify the defects correctly. This can be done with neural networks. With an automatic surface inspection system it is possible to gain a consistent inspection result covering 100% of the surface. The final task for the system is to judge if the product fits the intended use.

X. REFERENCES

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