Improving Periodic Defect Detection in Hot-Rolled Long Products by Means of Combination Between Eddy Current and Vision

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.


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Periodic defect roller marks (PDRM) (Fig. 1) are still an important problem for hot-rolled long products, affecting all grades; among them is the high-margin engineering steel production with specific lower T° rolling conditions, increasing roll crack occurrences due to fatigue stress. Most PDRMs are caused by groove cracks (GCs). An early detection of GCs as well as their identification is of paramount importance to improve the profitability of steel plants, and in many cases their survival. This paper will discuss the benefits of a new solution called EDDYeyes, synchronizing eddy current (EC) testing and Vision in real time. This is a complex solution that includes digital EC signals acquisition with on-time treatment and high-speed Vision systems, with high-quality LED lighting and complex math algorithms to give faster and more accurate defect information.

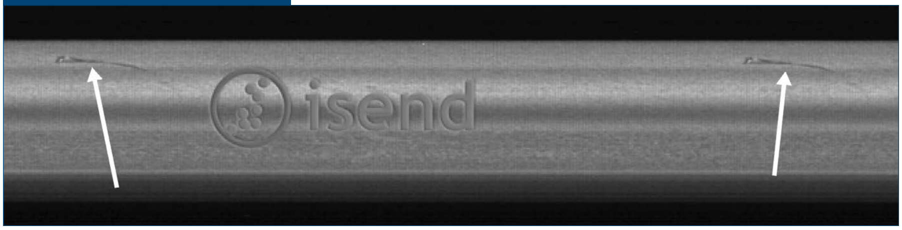
Discussion

The Problem Identification — Periodic defects caused by roll marks are one of the rolling mill's biggest issues. A broken roll generates periodic defects until it has been fixed and will affect every delivery to customers. The on-time PDRM detection has a direct impact on the income statement of the rolling mill because all defective coils must be sold at lower prices and delivered to less profitable customers. To be effective, defects must be quickly confirmed and the guilty roller identified.

Until now, several methods have been used for the detection and confirmation of PDRM, among which the most prominent are eddy current[1] and artificial Vision, used separately. In both cases, there are deficiencies. EC is very reliable, but it isn't intuitive, and it usually requires a delay of more than 1 hour for visual recognition. On the other hand, artificial Vision is intuitive, but it is often not reliable due to harsh environmental conditions such as steam, dirt, water, etc., and can't ensure optimal images. In both cases, the necessary investigation time is a real loss. However, the evolution of technologies allows a new approach to improve dramatically the PDRM early detection.

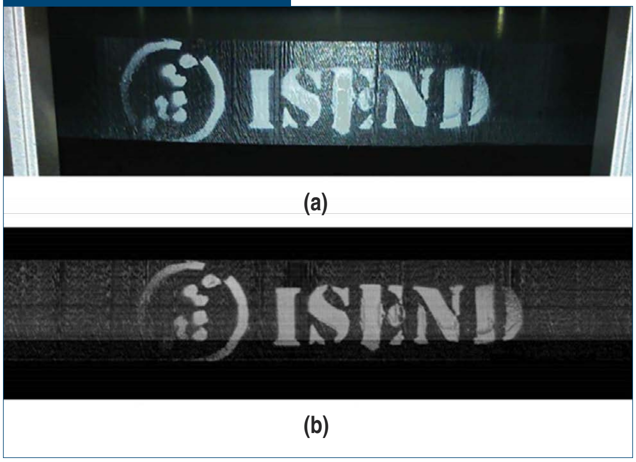
The Ideal Solution — The ideal solution would combine the benefits of eddy current with those of the image. For this, it should be as reliable as the first and as intuitive as the second. Examples of both

Figure 1



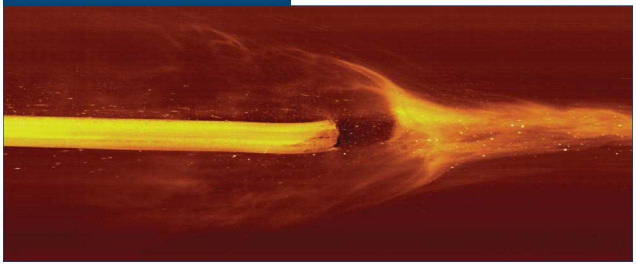
Picture of periodic defect roller marks (PDRM) taken from EDDYeyes.

Figure 2



Vision comparison between static picture (a) and an EDDYeyes picture simulation at 99 m/second (b).

Figure 3



Wire rod nose during hot rolling process at 99 m/second.

methodologies in a reasonable and logical way were already explained[2] with an application for the final user.

A new family of solutions has recently been introduced in the aluminum and steel industries, synchronizing EC as a primary detector with artificial Vision as a confirmation element as well as a secondary detector. This makes it possible to detect periodic defects early and drastically reduces investigation time. Additionally, this technology allows discrimination between random-type surface defects (scab, rolling scabs, overlaps, overfill, etc.) from those due to GCs, which produce repetitive surface defects.

An Innovative and Proven Solution — EDDYeyes technology is the result of the ISEND's work in this field.[2] The key factor is not separately adding eddy current technology and Vision but synchronization of both tools based on production parameters.

This technique consists of integration in real time and with a high degree of accuracy between the signal coming from the eddy currents and an artificial Vision system that captures images of all the signals potentially due to defects. The greatest difficulty is the synchronization of both elements and their process in a very short time, by using artificial intelligence algorithms, so that any alarm can be immediately verified visually even if the alarms is under the threshold set up by the users. As a result, good-quality images carry out the surface defect confirmation.

Both technologies used separately are present in various ways in the market, but the integration between the two is achieved for the first time with EDDYeyes, since it is not a simple integration between systems, but a whole development that optimizes the results and therefore should be considered as a single system. EDDYeyes has been developed in the most demanding conditions, with wire rod rolling at temperatures at 1,100°C and 110 m/second speed with vibrations.

The development has been carried out taking account as a test element the 5.5-mm wire rod produced at 110 m/second, the most demanding conditions in comparison with bigger sizes and speeds.

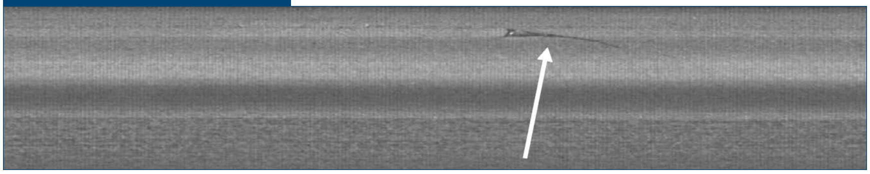
To develop EDDYeyes, it was necessary at first to use a workbench able to reach speeds of 100 m/second (Fig. 2), and in a second step a real installation in rolling mill customer facilities (Fig. 3).

During the development, multiple tests were carried out that have subsequently been confirmed in real environments.

Three Improvement Areas — The three major areas of improvement this method provides in the detection of PDRM are:

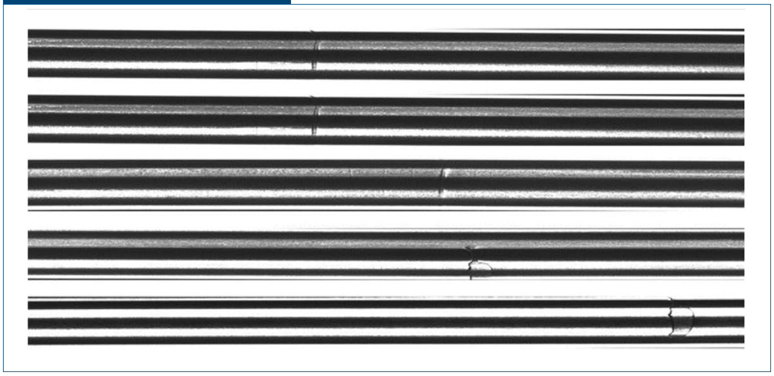
- Early confirmation of periodic defects that occur before the defect violates the alarms configured in the standard eddy current system for short defects.
- Immediate identification of the roll causing the defect.
- PDRM identification of defects that are not detectable by eddy currents (Fig. 4).

Figure 4



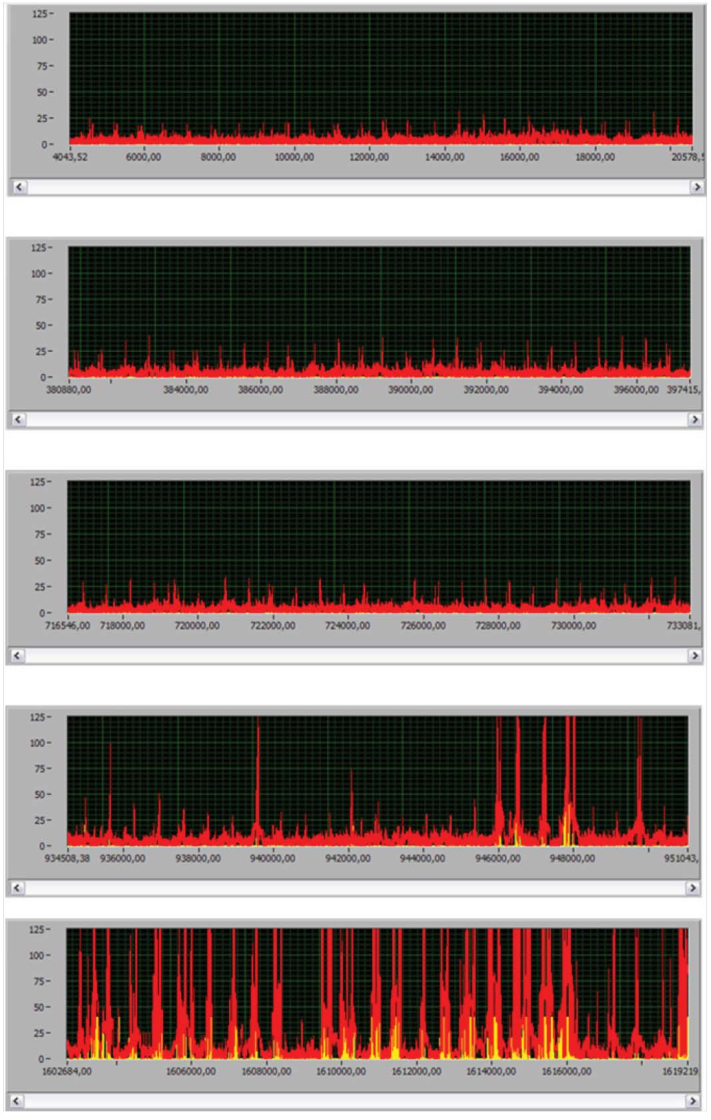
A typical roller crack defect.

Figure 5



Evolution of a PDRM.

Figure 6



Eddy current amplitude evolution.

Early Detection of PDRM — During the rolling process, the roller with GC starts with small empty slots that evolve and grows larger and larger (Fig. 5). Once the deteriorated groove begins to mark the material, these marks will be enlarging, achieving a size that will make them detectable by the eddy current technology. With artificial intelligence algorithms, peaks of amplitude can be detected that obey a certain frequency, even when EC signals are below the threshold of noise or off the alarm set by the users.

These algorithms allow for an order to be launched in the artificial Vision system to take and save images with that frequency and present the user with the real image on the screen, being able to decide when the rolling mill must be checked for cleaning, repair or replacement options.

In an analogous way, and using algorithms, the roll that is producing the mark can be determined with a good approximation.

Identification of Periodic Defects Not Detectable by the Eddy Current System — The artificial Vision system is not limited to being a mere confirmation element, but taking advantage of its potential, it acts as a second detector for those surface defects that, due to their morphology, do not produce appreciable signals due to EC. Again, using mathematical algorithms, periodic patterns can be obtained that may be due to potential defects. In a similar methodology to the previous section, whenever a periodic signal appears, the system will notify an alarm and present to the operator the images of the area of the material where it is produced.

PDRM Investigations Without Vision — In this situation, it is necessary to wait for the combined size/thermal signatures' signals from groove cracks for an indeterminate number of coils before confirming that a PDRM is present.

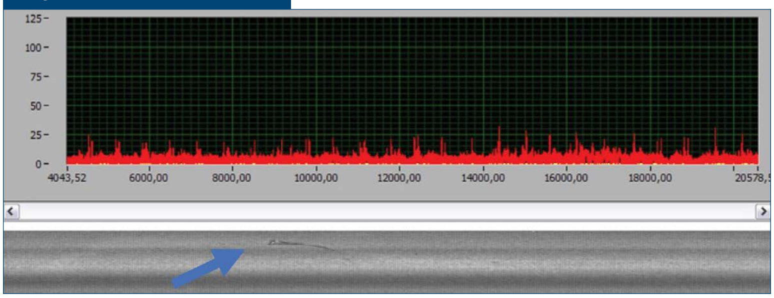
With the traditional eddy current solution, the analysis must be performed by graphics provided by the equipment. As a consequence with a 2.5-metric-ton coil per produced every 2 minutes, many defective coils will be rolled: 20 mn ⇔ 25 mT ⇔ one truckload. Fig. 6 shows four different stages of graphs that represent the peak amplitude evolution (Table 1). At the

Table 1

Eddy Current Alarm Log

Time	ID	Batch ID	Coil Sequence	Diameter	Mat ID	Pulses	Alarm	Roll ID	Level	PD alarm
15:10	XXXX58	4	26	21	***BCR	92	F = 13.18 Hz	27	1000	Yes
15:12	XXXX04	3	6	21	***CRM**	9,833	F = 12.68 Hz	27	5000	Yes

Figure 7



Comparative data with eddy current and Vision.

beginning, the defect is small and graphics don't show anything significant. Obviously, the threshold of the alarms could be set up lower, but the consequent side effects are confusing.

Even though an artificial intelligence algorithm is used to detect periodical peaks in the alarm plane, it isn't easy to confirm if the cause of the defect is a groove roller crack or other signal like vibration type.

Once several peaks go over the alarm threshold, the operator can suspect that a GC is present. However, the experience of previous occurrences is necessary to get a confirmation.

Looking at Fig. 6, there is some important information that can be summarized.

A PDRM shows an evolution over time. The signal amplitude in terms of points gives an accurate vision about the severity of the defect during the rolling mill operation.

The graphics (Fig. 7) also show a frequency between amplitude peaks. This can be used to identify the GC periodicity in combination with production parameters such as finishing roller diameters.

The users can set up the alarms to decide in which moment a signal can be considered as a real alarm. With the Vision module contribution, the alarms can be set up at lower levels than the standard one from eddy current because the confirmation will be done specifically by the pictures produced.

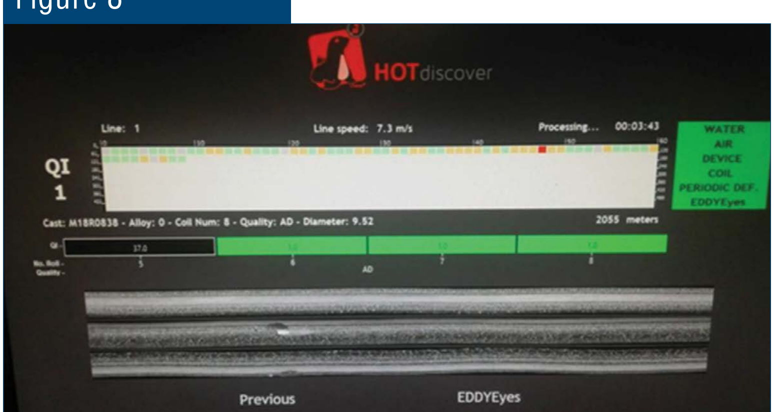
PDRM Investigations With Vision — The main difference by using the pictures is that once a suspect frequency in peaks is shown, the operators can look at the picture given by the Vision module. To do that, it's only necessary that frequency and peaks don't remain as the most important information from EC.

The system will produce a red alarm of a potential PDRM, including the frequency of the peaks, and then it will take pictures of the areas of the material where these peaks are produced (Fig. 8).

Then, the operator can see the alarm log, where the system will show the frequency and the related roller as well as the picture. Peaks are less important than the frequency, because the picture adds the complementary information about the defect geometry.

This Is the New Technological Approach — To comply with this requirement, the basic technology must allow the real-time synchronization of the electromagnetic alarms and the image. The synchronization of both is a key element and will produce real-time images of potentially defective areas. To achieve results applicable to obtaining high-speed products such as 5.5-mm wire, the Vision equipment (Fig. 9) must be fast enough in

Figure 8



Map and Vision pictures as shown in the operator screen.

terms of sampling frequency, typically on the order of hundreds of thousands of images per second.

But it is not the only element of development; also the lighting system must be specially designed to achieve a reflection of light according to the intended use. Poor lighting equipment could create false alarm detection.

To get the best results, the system tracks the following steps:

1. The eddy current tester measures amplitudes and phases of the eddy current in the surface of the material.
2. A development of artificial intelligence based on powerful algorithms can detect peaks of amplitude even below EC alarms and the noise level suspected of being produced by the groove roller crack.
3. Once the guilty frequency has been determined, the system will light an alarm of potential defect due to a roll break and will take images with that frequency and present them on the operator's screen.
4. The operator will analyze the images and make the corresponding decision.
5. In parallel, the artificial Vision machine takes images of all the material.
6. A development of artificial intelligence based on mathematical algorithms will detect periodic image patterns that may be associated to the equipment signals of eddy currents or not. If not, the system will light a potential defect alarm due to the presence of images available to the operator.
7. The system will discard those images that are not associated with either a defect alarm or a suspicious frequency.

In summary, the system will allow the detection of periodic defects whether they are detectable by eddy currents or if they present a similar image pattern and will be optimized so that only images of potentially defective areas are stored, discarding the rest.

EDDYeyes combines a series of elements that have already been tested and optimized in several rolling mills:

1. Digital technology of EC developed by ISEND.
2. High-speed image capture system with a resolution higher than 0.5 mm for 5.5-mm wire manufactured at 110 m/second.
3. LED lighting system developed by ISEND to improve the quality of the images.
4. Software for the analysis of periodic signals in the amplitude of the EC.

Figure 9

On-line one-strand EDDYeyes industrial unit.

5. Software investigations for periodic image patterns.
6. Synchronization system.

Conclusions

The integration of EC technology and Vision emphasizes the capabilities for investigations confirming the occurrences of PDRM in hot rolling mill production. That integration generates a big data model for a new on-time surface defect management strategy replacing the 50% GC late detection efficiency with only the EC.

In addition, it opens the door to new research based on the combination of reliability given by EC and intuitiveness given by Vision, therefore allowing a new methodology for roller use and roller stock management policy.

Duplications of information (EC + Vision) along the product line are easy to install, allowing all the teams from shift operators, production management and control to understand on-time the RM surface quality with any kind of new functionalities (e.g., smartphones).

In this report, it has been explained how the new defect detection system based on the integration between eddy currents and artificial Vision developed by ISEND and called EDDYeyes contributes to the best detection of PDRM through:

1. Immediate and visual confirmation of periodic signals detected by eddy currents.
2. Immediate identification of broken rolls.
3. Expansion of the traditional capabilities of the eddy current testers to the treatment of periodic images to increase the typology of detectable defects.
4. User-friendly solution.

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