Advanced sensor for on-line topography in continuous lines

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More and more stringent customer requirements and the need to increase productivity are two main reasons pushing the steel makers to deliver higher surface quality strips. To better control and improve the surface properties, CRM has developed, in collaboration with Sidmar, a sensor grabbing highly magnified images of the moving product.

The selected measurement method is based on the principle of triangulation: a very thin line is projected on the surface and the relief is determined by analysing line deformation of the line. The result is a sensor able to assess on-line the 3D topography.

INTRODUCTION

Complex metal forming, high quality in term of corrosion resistance, more and more stringent customer requirements and the necessity to increase productivity are some of the numerous reasons that face the steel makers to deliver strips with guaranteed high quality surface.

Although major improvements have been achieved during the last years, the strip surface, and especially the roughness (Ra), is not yet under control.

On-line topography measurements along the whole length of the strip will help to reach a better understanding of the influence of various production parameters on the strip surface quality. Moreover, it will allow delivering a certificate of conformity for the whole coil. As well coated, un-coated, random (e.g. EDT) and deterministic (e.g. EBT) surfaces are concerned.

To meet this target, a topography sensor has been developed by CRM. It uses an on-line microscopy method coupled to an advanced image processing.

MEASUREMENT PRINCIPLE

On-line microscope

For other applications requiring on-line highly magnified images of surface, CRM has previously developed a sensor using an optical microscope to grab images of moving products. (Fig. 1)

It is composed by:
- a microscope objective and associated adaptation optics for camera,
- a CCD camera coupled with a frame grabber,
- a laser light source,
- a motorised positioning and focusing system,
- a distance sensor,
- a control unit with I/O boards,
- and, for roughness measurement, a laser line projection unit (described hereafter).

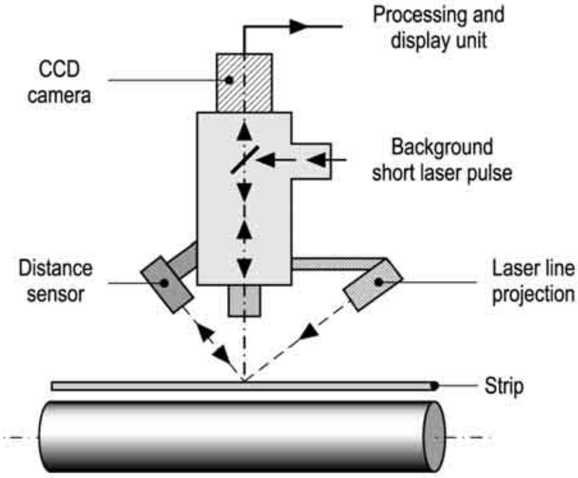

Fig. 1 - Optical configuration of the sensing head

Fig. 1 – Configuration optique de la tête de mesure

Relating to the target application, the width of the field of view can be adjusted from 250µm to 2500µm. This is reached by the use of high magnification objectives. This implies a small depth of field (i.e. a few micrometers depth in which the image is sharp) which compels to locate the sensor with a very high accuracy in order to get not blurred images.
The combination of the CCD size and the objective allows reaching a precision as high as 0.1µm for the highest magnification.

To freeze the image of the moving product, a short laser pulse (10ns) is used as source of illumination (flash principle).
For a field of view of 600µm, it will so be possible to observe moving products reaching a speed of 20m/s.

On-line conditions, such as vibrations, strip and coating thickness fluctuations, will induce variations of the strip surface to sensor distance, which can typically reach 1mm.
As a consequence, this distance has to be very accurately measured to well position the microscope and to only grab images when they are perfectly focused. Due to the small depth of field and to get focused images, an accuracy of 1µm has been chosen for the distance sensor.

Finally, to meet a surface stability as high as possible in operating position, the on-line microscope has been installed in front of a roll.

Image acquisition strategy

Based on the distance measurement, the strategy is to place initially the microscope in such a way that the focal distance is situated in the middle of the range of the fast distance variations, due e.g. to roll eccentricity. In this manner, the surface is focused at least twice per roll revolution. The slow rate amplitude variations (due e.g. to tension variations) are compensated by the automated displacement of the microscope each time the measured distance is completely out of the focusing range.

Each time the distance sensor detects a value equal to the focus distance, a laser pulse is sent and an image is acquired (Fig. 2). Then, it is processed to extract the interesting parameters.

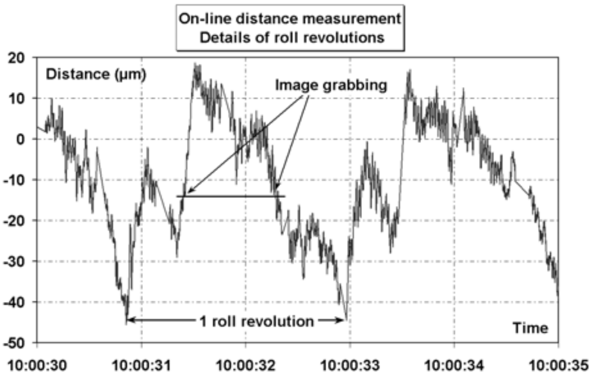

Fig. 2 - Image grabbing principle during one revolution

Fig.2 - Principe d'acquisition d'images pendant une révolution de cylindre

Reference method

The stylus mechanical measurement presently remains the off-line reference method to assess the roughness of a surface. With this method, the height of a profile is measured along a defined length and the arithmetic roughness (Ra), as well as other characteristic surface parameters, are calculated from this profile.

The Ra value is the universally recognised, and largely used, international parameter of roughness. Let us recall what it represents.
The mathematical formula is given below:

$$Ra = \frac{1}{l}\int_0^l |z(x)| \cdot dx \,,$$

which is the arithmetic mean of the absolute height of peaks and valleys of the roughness profile around the mean line. (Fig. 3)

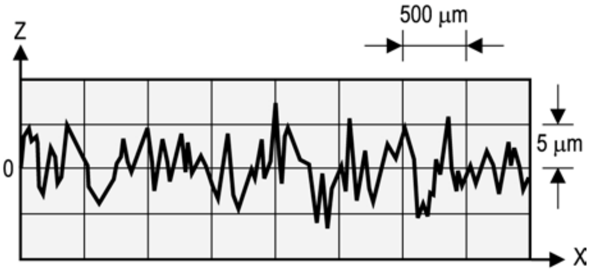

Fig. 3 – Roughness profile measured with a mechanical stylus

Fig. 3 – Profil de rugosité relevé au stylet

A cut-off is generally applied to remove or restrict unwanted data in order to look at wavelengths in the region of interest. For roughness calculation, it is a current practice to eliminate waviness that shows a wavelength higher than the basic roughness. One of the most standard cut-off is 2.5. For this value, a profile length of 12.5mm is used for the calculations.

The range of measurement required by steel producers and users covers arithmetic roughness values from 0.3µm to 3.5µm.

CRM method

Using the triangulation principle at a microscopic scale, the method developed by CRM consists in the projection of a very thin laser beam line (a few micrometers wide) onto the surface. The deformation of the observed line is directly in relation with the height of each point of surface by which the laser beam line is reflected.

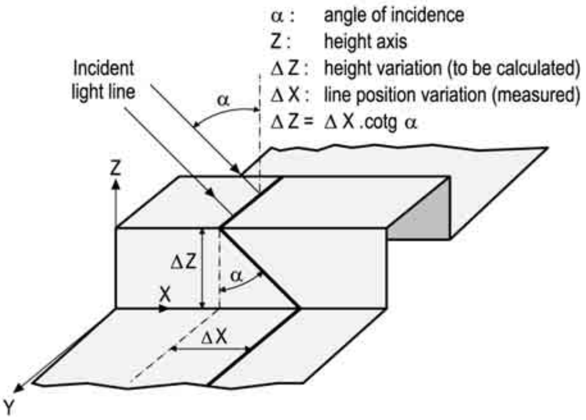

Fig. 4 – Principle of height measurement

Fig. 4 – Principe de mesure de hauteur

From this principle, illustrated in Fig. 4, the basic formulas for the height measurements are:

$$\Delta Z = \Delta X \cdot \mathrm{cotg}(\alpha)$$
$$\Delta X = \Delta Z \cdot \mathrm{tg}(\alpha)$$

A sample of an image containing such deformed line is shown in Fig. 5.

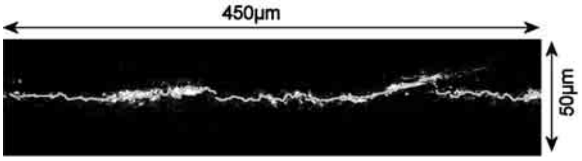

Fig. 5 - Part of acquired image with line projection

Fig.5 - Portion d'une image avec projection de ligne

This line follows the surface relief and, after an image processing, results in the profile of the surface, from which is calculated a local arithmetic roughness using the formula mentioned previously.

The range of measurement to be covered requires a high precision technique fulfilled by the use of a combination of a high-resolution camera and a high magnification objective. This leads, in this example, to a view of 450µm of width.
To strictly compare the optical method to the mechanical one, approximately 30 images are required to reach the same length of measurement (12.5mm).
Finally, a mean value recalculated on the last 30 images is determined in real time after each acquisition of an image, resulting in a continuous measurement of the roughness Ra along the strip.

LABORATORY TESTS

A first step has consisted in the validation of the method in laboratory conditions. For that purpose, various samples have been collected covering different product textures (EDT, EBT, PRETEX) and different values of roughness.

To strictly validate the method, small rectangles have been engraved on these samples. In that way, areas were well defined and can be used for different measurements. In these areas, scanning has been done with a mechanical stylus and also with the microscope line projection method. The results were 3D representations of the defined areas, allowing a fine comparison of the calculated topography of the surface. Such 3D result is shown in Fig. 6 with a grey level map representation, each grey level corresponding to a specific height.

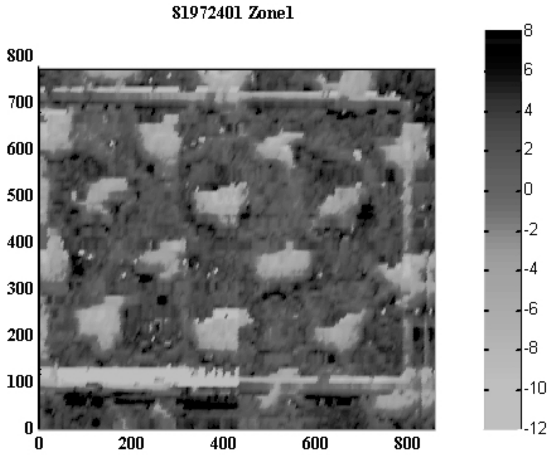

Fig. 6 – Validation of the method
3D grey level map

Fig.6 – Validation de la méthode
Carte 3D en niveaux de gris

In the same area, a profile line has been recorded by the use of the two methods. Fig. 7 shows one of the results of this test. The small observed differences are mainly due to the difficulty to get exactly the same position in both methods. However, the profiles are nearly identical and demonstrate the high precision of the new method developed by CRM.

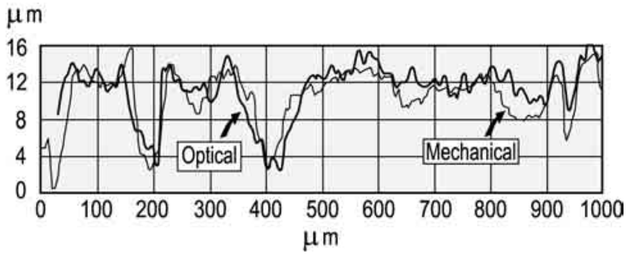

Fig. 7 – Validation of the method
(light: mechanical stylus, bold: line projection)

Fig.7 – Validation de la méthode
(fin: stylet mécanique, gras: projection de ligne)

This step has permitted to successfully validate the new optical method.

ON-LINE APPLICATION

After the laboratory validation on industrial samples, on-line tests have been conducted at Sidmar at the exit of the CAPL line (after the skin-pass) during several campaigns.

These tests have demonstrated a high correlation between the mechanical measurements made at the head or at the tail of coils and the corresponding value obtained by the on-line microscope (Fig. 8). This has been done as well for deterministic surfaces (EBT texture) as for non-deterministic surfaces.

The graph of Fig. 8 shows a range of variations reaching +/-20% of the reference mechanical measurement. As this last one insures a precision of +/-10%, the new method seemed to be more dispersed. However, this can be easily explained by the fact that the comparison was made with a mechanical measurement done at the head or at the tail of the coils, i.e. at a place where the running conditions are very specific due to the welding required between successive coils (mainly, a change in the traction force).

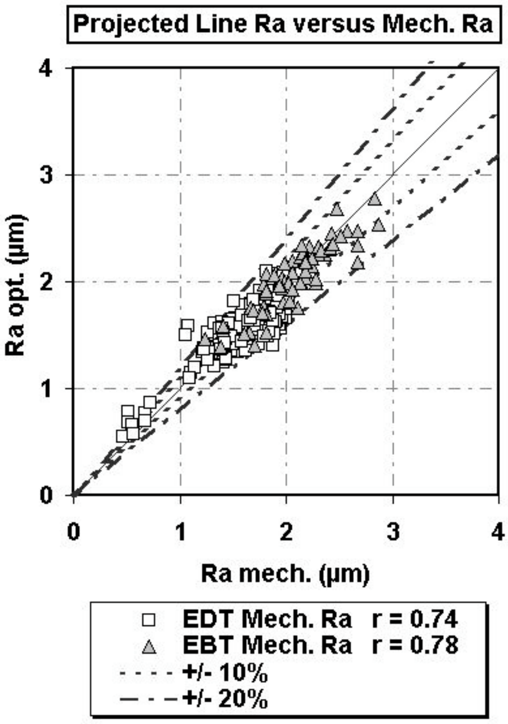

Fig. 8 - Roughness global results of preliminary tests
on CAPL line of SIDMAR

Fig.8 – Résultats des tests préliminaires de rugosité
menés sur la ligne CAPL de Sidmar

To finer validate the sensor, specific tests have also been done on coils on which production conditions, mainly skin-pass pressure, have been modified to reach different roughness values.

These coils have then been measured with a mechanical stylus system on the inspection line all along the coil length at positions determined by the variations of the production conditions.

The comparison between mechanical (stylus) and optical (microscope) measurements have shown an even better correlation than the comparison with the measurements carried out on the coil heads and tails. (Fig. 9)

The dispersion is also far lower compared to the mechanical measurement, almost all the points are in +/-10% range of variations.

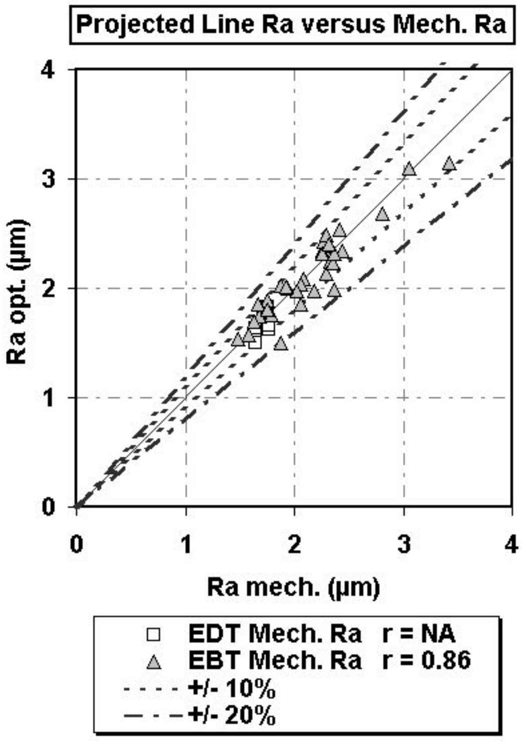

Fig. 9 - Roughness results of specific coils of tests

Fig. 9 – Résultats des mesures de rugosité sur bobines tests

CONCLUSIONS

In conclusion, this advanced sensor provides the opportunity, by a real time analysis of the surface, to enhance the production quality. It gives information that can be used to adjust production conditions and to reach the Ra range required by the customer.

Moreover, specific coil tests have also confirmed that the head and the tail of coil are not sufficiently representative of the entire coil. Indeed, the production conditions must be slightly adapted to let passing the welding in the skin-pas, inducing a change in the resulting surface characteristics. This gives a supplementary advantage to the on-line system that measures the surface not only at the head or tail of the coil but also all along its length. It can also be used to deliver a conformity certificate to the customer.

The system has been licensed by CRM to Amepa, a German company, in order to commercialise it.

CV

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