OPTICAL ONLINE SENSING OF THE CLEANLINESS OF METAL STRIPS[1]

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Abstract
A new optical method which allows the remote, contactless real time measurement of the cleanliness of metal surfaces is presented. A pulsed laser is used to ablate the surface contaminant layer. The light emitted from the created plasma is quantified as a measure of the surface cleanliness. The laser power is set well below the surface damage threshold. This technique can be mounted online and measure cleanliness even on rapidly moving parts as found in strip galvanizing lines. It is demonstrated that this new laser equipment for cleanliness evaluation is suitable for a precise and automatic real time evaluation of the strip cleanliness after the cleaning section in a continuous hot dip galvanizing line. Three types of results are discussed: The laboratory tests showed that the new technique is more reliable and repetitive than the adhesive tape test and can be used to calibrate the system in the same scale as provided by the tape test. The tests made in line where performed at the input and output of the cleaning section, testing different conditions of the bath and different configuration of nozzles and brushes. The new detector design permits a more portable online system that can be easily moved within different locations (such as input and output of the cleaning section or even between plants).
Key words: Cleanliness; Online NDT; Laser; Contactless.

[1] *Technical contribution to the 50th Rolling Seminar – Processes, Rolled and Coated Products, November, 18th to 21st, 2013, Ouro Preto, MG, Brazil.*
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1 INTRODUCTION

The existent techniques for cleanliness evaluation rely on laboratory procedures not performed in real time. They are slow, cannot be automated, require specialized personnel and are based in sampling small surfaces thus not providing information on the homogeneity and distribution of dirt. One of the most common techniques takes a sample of the surface dirt by means of an adhesive tape. The contact of the tape with the surface removes part of the dirt that sticks to the tape increasing its optical opacity, which is later determined in the laboratory. Alternative techniques are based in quantitative analysis of the dirt removed from part of the surface and compare it with standards or measuring the carbon residues by chemical techniques.
The cleanliness of the strip surface before continuous hot dip coating is a key parameter to ensure both the quality and the efficiency of the galvanizing process. The difficulty of strip cleanliness online determination often forces redundant cleaning stages with their corresponding increase in cost production and effluent treatment. Moreover, problems with surface cleanliness are usually only detectable once a strip quality problem is encountered. It is demonstrated that this new laser equipment for cleanliness evaluation is suitable for a precise and automatic real time evaluation of the strip cleanliness after the cleaning section in a continuous hot dip galvanizing line.
The new equipment is an improvement over another innovative approach: the laser ablation and acoustic detection technique, that was used to measure in real time in the production line the cleanliness of cold rolled steel sheets.[1-3] It has been possible to relate with an analytical expression the relation between the amplitude of the signal and the density and size of the obscure dirt particles in the surface.[4-6]
The instrument introduced here also uses the laser ablation of the surface dirt but on one hand uses an eye safe laser and on the other the detection is made optically with high sensitivity detectors that allow a simpler and more compact installation for online versions.
Three types of results are discussed:

- trials with a portable device with still sheets, used to validate the method and compare it with other techniques such as the adhesive tape test and the photoacoustic laser ablation test;
- an in line test performed in the continuous Hot Dip Galvanizing line #2 (HDG2) of Ternium Siderar, at Canning Plant, Argentina;
- a new design for the detectors that has permitted the use of much smaller optics, leading to a rugged system that can be located farther from the surface (more than one meter) and allows the measurement at an angle, allowing a side installation instead of a top or bottom installation used before

2 MATERIALS AND METHODS

In Figure 1 a schematic description of the equipment used for the relative cleanliness determination (RC is expressed with 100 meaning clean) based on the laser ablation and both acoustic and optical detection. A pulsed infrared laser emitting up to 5 pulses per second is used for the dirt ablation, and the signal is detected by an optical device (lenses, filters and detector) and a microphone. The signal is further electronically processed, conditioned and acquired by a computer that processes the signal and controls the equipment. The method relies in the ablation of the surface dirt by a very short (less than 10ns) laser pulse and analysing the emitted light from the plasma plume generated after the ablation process, as illustrated in Figure 1. The acoustic detector is also indicated for the comparison of the two methods.

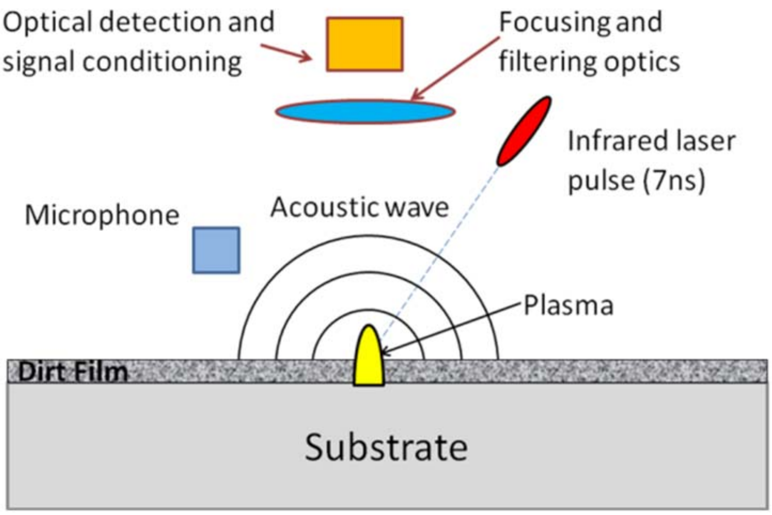

Figure 1. Schematics of the technique. A laser pulse ablates the dirt and an optical detector measures the amount of light emitted by the plasma plume.

3 RESULTS

3.1 Adhesive Tape Test Comparison

A portable device was used to compare both methods with the results obtained with the well-known adhesive tape test. This last test can only be performed with a still sample, and the tape is used to extract the surface dirt for a later measurement of the film optical transmission (an indication of the amount of dirt removed from the surface by the sticky tape). The portable device (Figure 2) included an acoustic detector besides the here described light detector.

The tape test averages over a large area, providing a smoother reading but no indication of the fluctuations in the dirt distribution. The measured results for this test were (in units of reflectivity) IR=91.6±3.9 for the optical signal, IR=91.6±4.3 for the acoustic signal and IR=91.8±3.5 for the tape. It must be stressed that the error indicates actual fluctuations in the distribution and not precision of the method.

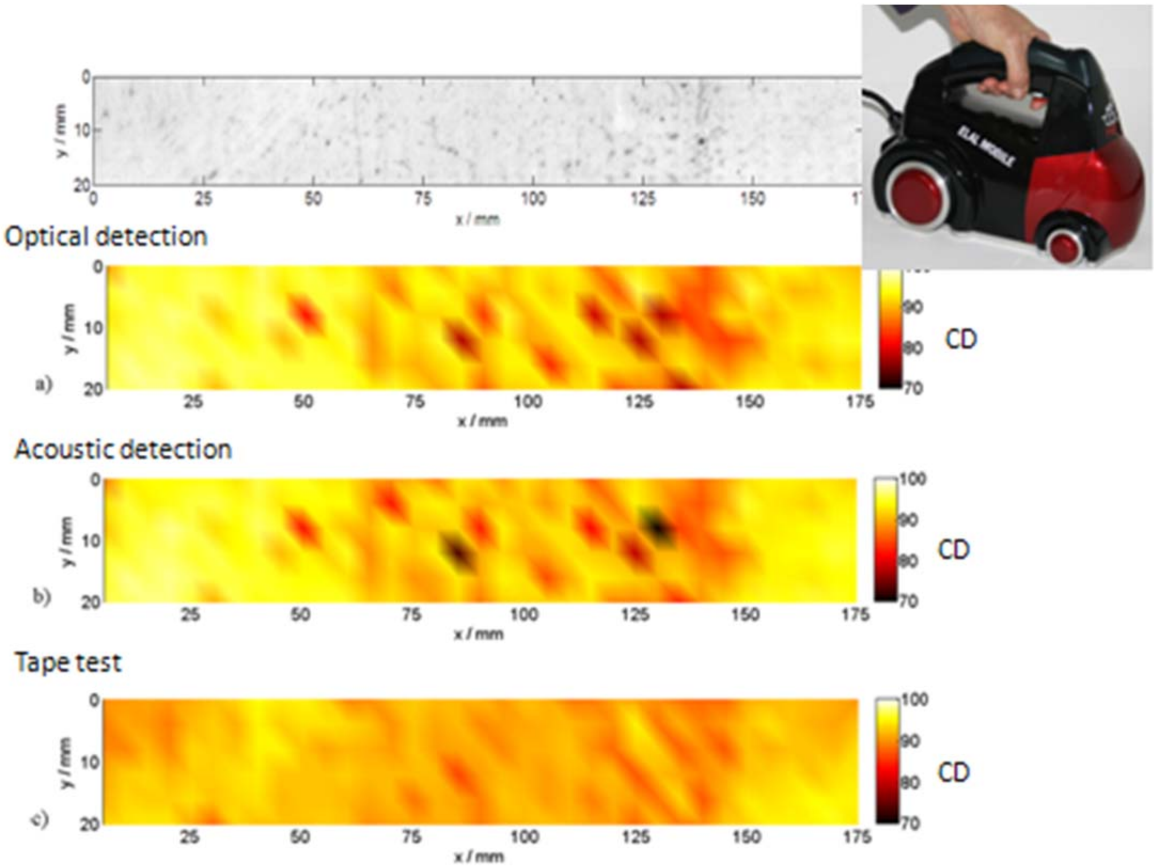

Figure 2. Inset: the portable equipment used for the test. Upper figure: image of the tape after removal. The color coded images are respectively the measure scan for the optical, acoustical and tape.

3.2 Online Measurements

A second equipment was used for the online measurements performed at the galvanizing line of Siderar (Ternium) located in Canning, Argentina. The measurements were performed at the entrance and exit of the cleaning section for two different conditions of the cleaning bath: Condition A: the cleaning system had 8 days of continuous use after resetting. This condition corresponds to 60% of the life cycle of the washing solution. Condition B: less than 24 hours from resetting.

At the entrance the strip has the dirt contained within a thin oil layer as delivered from the cold roll mill. This tests was used to show the correlation of the signal obtained from the acoustic method and the optical detection method (Figure 3).

As no sample can be extracted from the line for comparison with other laboratory techniques, a reference value was taken assigning a relative cleanliness degree RC=0 to the worst case measured and a value RC=100 for the measurement in absence of plasma at the surface.

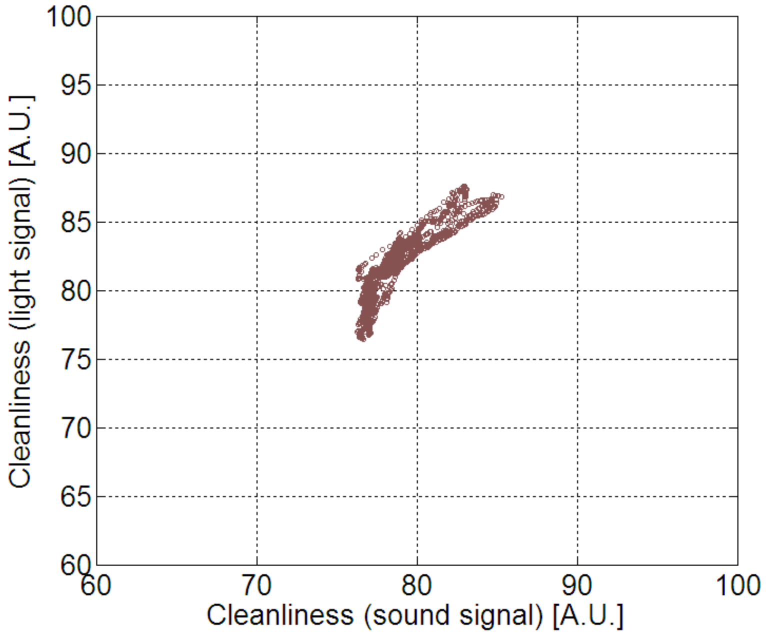

Figure 3. Plot of the optical signal as a function of the acoustic signal proving the sharp correlation between the two.

Sampling was taken at 1Hz at the bottom side of the strip, at 150 mm from the left edge, and this was kept along the entire test in order to compare the different operating conditions.
Each value was taken after averaging 30 shots, and hence each number is the average of the last 30 seconds of the process. The average curve filters punctual fluctuations in the cleanliness due either to inhomogeneities in the strip or to local fluctuations in the cleaning process.
For the same bath conditions a test was performed at the exit of the washing stage. The alkaline washing unit of the HDG2 plant in Canning (Argentina) has five stages.

- predegreasing: first stage of the process where the alkaline solution is injected by several headers with 10 nozzles each. Each header can be manually operated.
- degreasing I: polyamide brushes are used with additional injection of alkaline solution. Each brush acts on one face with a backup roll and each pair brush/backup roll are alternated in the two surfaces. After each brush a header with 10 nozzles is located.
- degreasing II: similar to degreasing I. Two pairs of squeegee rolls are placed at the end of this stage.
- rinse: industrial water is injected for this stage through 11 pairs of headers with 10 nozzles each. Two pairs of squeegee rolls are placed at the end of this stage.

Figure 4 shows a picture of the equipment installed at the output of the washing section just before the entrance of the furnace.

Figure 4. Equipment installed at the output of the washing section**.**

To evaluate the sensitivity of the measurement device to the changes in the parameters of the washing unit, different parts were sequentially deactivated or stopped, such as shutting down some nozzles, removing the brushes or changing the strip speed. An example of typical results is shown in Figure 5, where some of the operations show changes in the cleanliness, such as introduction or removing of nozzles or rolls. The lower plot shows that information can not only be extracted from the average value of the relative cleanliness but also on the fluctuations of the cleanliness, which increase with the strip speed.

3.3 New Compact Online System

As the laser propagates away from the source the beam expands due to diffraction. This fact decreases the laser pulse fluence (surface energy density) as a function of distance, limiting the maximum possible location of the strip surface to about 50 cm from the equipment, beyond that distance the laser fluence was not enough for dirt ablation. Besides this fact due to the small amount of light emitted by the plasma plume a large collecting solid angle was required (300 mm optical lens diameter). It is convenient to be able to locate the equipment farther away from the surface, for equipment safety reasons and to reduce the sensitivity of the measurement to changes in the distance (transverse movements of the strip).

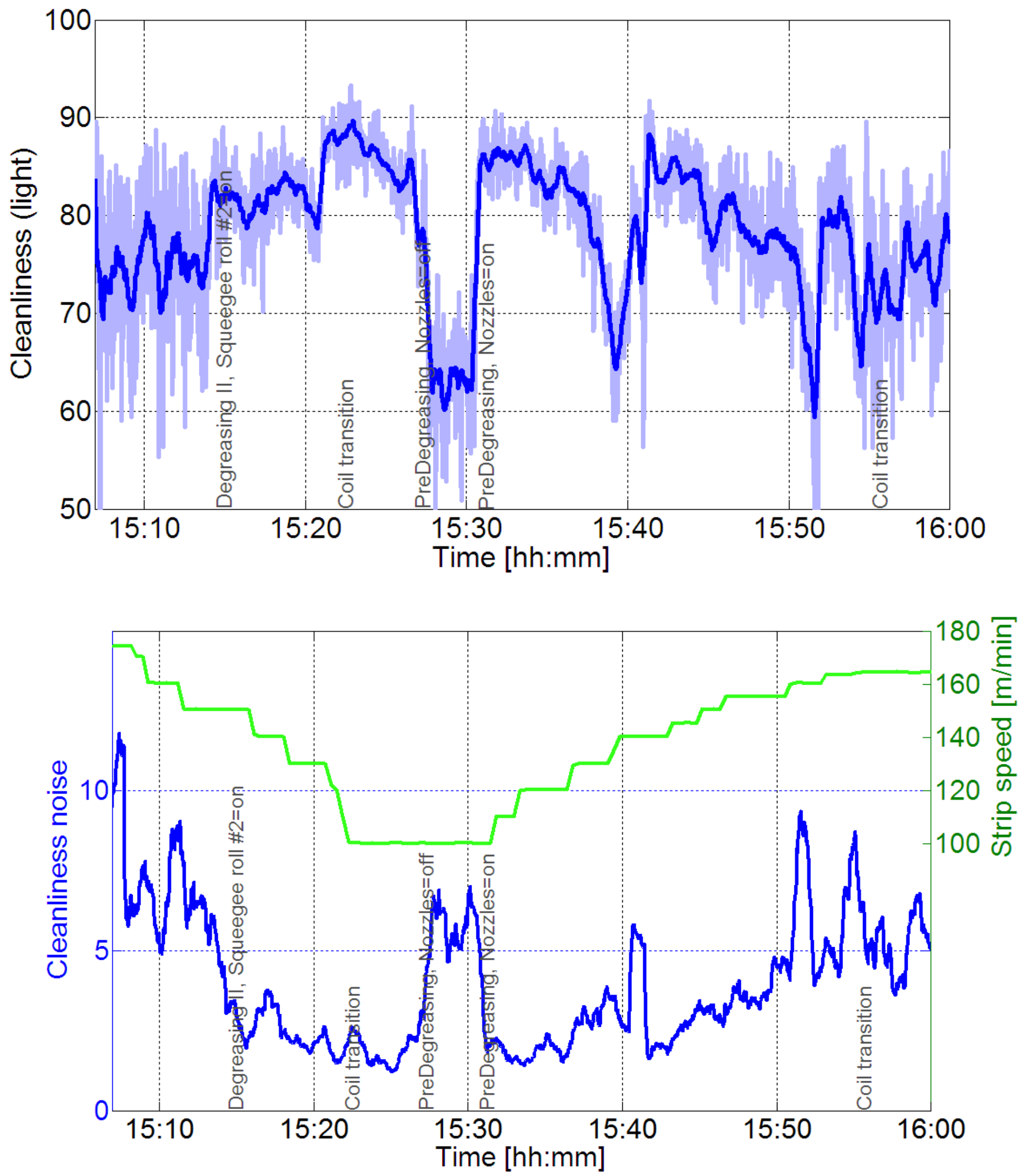

Figure 5. Condition B. Details of the measurement (upper plot). Effect of the strip speed (green trace) on the fluctuation of the RC (blue trace).

To overcome this inconveniences a new system was designed that incorporated a carefully designed optical collimator that located the laser beam waist around 1500mm from the equipment surface, providing a uniform ablation range between 1m and 2m away from the surface. To test the uniformity of the ablation a microphone fixed to the strip was used as a measure of the amount of ablation. The results as a function of the distance are shown in figure 6-a, where a 4.5% change with distance was determined.

The collecting optics was reduced in diameter to 50mm, which together with the increase in the distance yields a decrease in the collecting solid angle of more than 350 times. This reduction was compensated by changing the detector for a more sensitive one (10.000 fold increase). In Figure 6b the detected signal as a function of distance is depicted (solid line is an exponential fit that allows the calibration of the signal with distance.

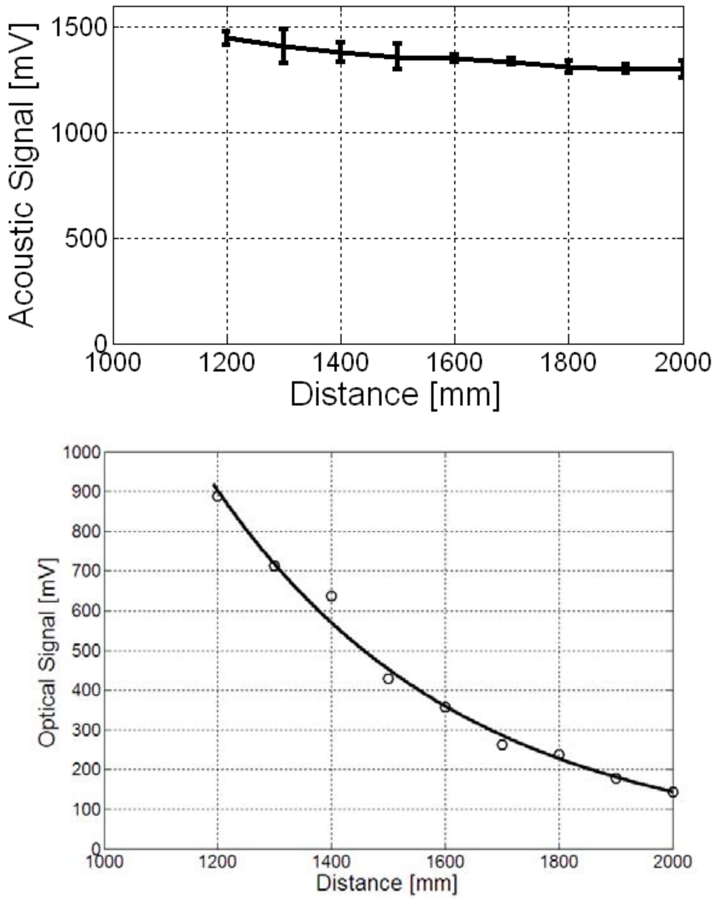

Figure 6. a) Acoustic signal measuring the amount of ablation, as a function of distance of the strip surface from the laser output. b) Optical signal as a function of distance of the detector from the strip surface.

4 DISCUSSION

The entire campaign is presented in Table 1. It can be seen that the different maneuvers have different impact depending on other conditions. Following in order, removing the predegreasing nozzles have the same impact at the beginning of the campaign (just after resetting the bath) and after 8 days of use. Quite different is the situation of the brushes of degreasing I, where they do not seem to have a significant effect with the reset bath, but are important as the campaign advances

Table 1. Average cleanliness and standard deviation for the different situations tested

Stage	Situation		Relative cleanliness Condition A	Relative cleanliness Condition B
Predegreasing	Nozzles	100%	80±3	85±2,5
		0%	65±3	62±5
		100%	80±3	85±4
Degreasing I	Brushes	100%	80±4	68±8
		0%	65±5	71±7
		100%	-	70±7
Degreasing II	Squeegees	100%	-	80±4
		50%	-	65±12
		100%	-	78±5
		50% used	55±12	-
		50% new	85±4	-
		50% used	57±14	-
Rinsing	Nozzles	100%	-	70±10
		0%	-	45±15
		100%	-	80±4
	Squeegees	100%	88±3	79±5
		50%	93±2	79±4
		100%	86±4	80±3

5 CONCLUSION

A new technique for surface cleanliness determination was demonstrated. It was shown that it correlates with alternative techniques such as the adhesive tape test (with the advantage of online capability) and the laser ablation and acoustic detection technique.

The technique was tested online before and after the washing section of a galvanizing line, proving its usefulness not only for quality control but also to determine the needs for services, and testing the efficiencies of any change or improvement made to the line such as new brushes, change of nozzle design, bath composition, among many others.

A new optical design was presented both for the laser collimation and the collection optics. This changes allows the installation of the system in a more flexible and safe condition.

Acknowledgements

The authors wish to acknowledge the contributions from the personnel of Siderar and particularly to Gabriel Cervellini for the access to the plant and help in the online tests.

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