LASER INSTRUMENT FOR DETERMINATION OF THE DEGREE OF CLEANLINESS IN COLD-ROLLED STEEL PLATE MANUFACTURING

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Abstract **Cold-rolled steel plate emerges from the manufacturing process with a thin layer of residual dirt that has to be kept under control for two main reasons: it may be indicative of deviations from normal functioning in previous manufacturing stages and it may impair the effectiveness of downstream operations such as painting, galvani-zing, etc. Standard measurements of this residual dirt are based on not trustworthy laboratory sample measurements, outside the production line. We developed a method that allows on-line determina-tions of the cleanliness degree for the whole manu-factured steel plate bobbin. Based on this method, we designed the first industrial instrument (ELMES I), which is now in operation at the final inspection line of the Siderar's plant at Ensenada (Buenos Aires)**

Keywords— Acousto-optical devices, Lasers applications, Industrial laser applications, Industrial research and development.

I. INTRODUCTION

The determination of the amount of residual dirt (cleanliness) of steel plates after cold rolling is crucial both for the effectiveness of downstream operations such as galvanizing or painting and as a control of possible malfunctioning of prior stages of the process. Existing methods for cleanliness determination are based on laboratory measurements outside the production line. The simplest and most effective method relies on the measurement of the transparency of an adhesive tape that has been stuck and removed from the surface to be tested. Other methods rely on the chemical analysis of the residues whipped (Ford, 1985) or burned off the surface (EUR, 1996). All these methods have three main drawbacks: they cannot be automated, they are performed offline, are time consuming, and they only sample a small portion of the plate.

In this work a new method that overcomes all the above mentioned drawbacks is described. The method relies on the ablation of the dirt film by means of a short laser pulse and the subsequent measurement of the sound emitted. The intensity of the sound turns out to be proportional to the amount of dirt and provides a direct measurement of the cleanliness of the surface. The technique can be used on-line, and automatically measures the cleanliness along the entire plate.

II. DESCRIPTION OF THE METHOD

The new method (Bilmes and Martínez, 1999) allows to measure in real time the dirt present on different types of surfaces. In the case of cold-rolled steel plates this measurement can be made directly on-line on the moving plate, or on samples. A schematic of the technique is shown in Fig. 1. A Nd:Yag pulsed laser is directed towards the surface to be tested and a microphone picks up the emitted noise that is correlated to the amount of dirt present on the sample. Part of the laser pulse is directed towards an energy meter that is used in order to normalize the acoustic signal and hence compensate the pulse-to-pulse fluctuations from the laser.

The method is based on the fact that the dirt on the surface is composed by a thin film of oil, soaps and solid particles. If a laser pulse of enough fluence (energy per unit area) and short duration (about 20 ns) impinges on the surface, a violent heating of the film takes place giving rise to its expulsion without damaging the plate. As a consequence of this interaction between the light pulse and the film, various phenomena

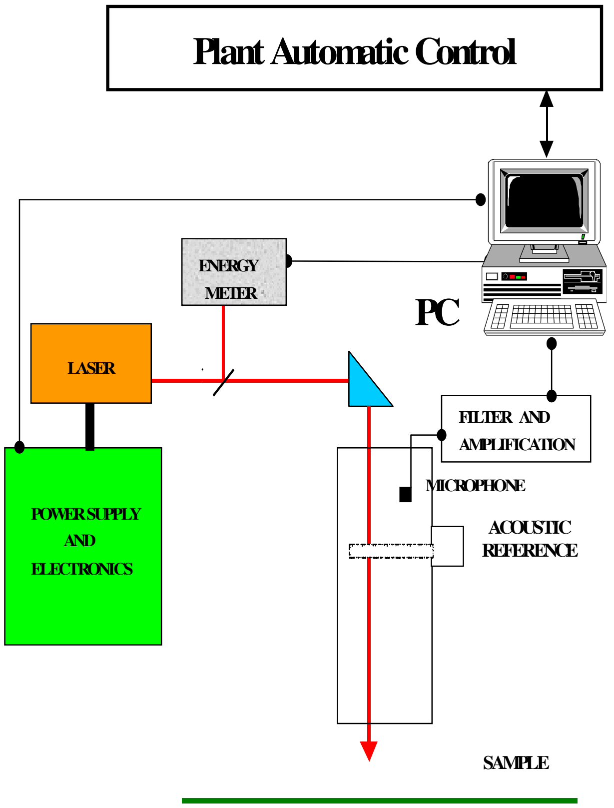

Fig. 1: Schematic of the technique (block diagram of the ELMES).

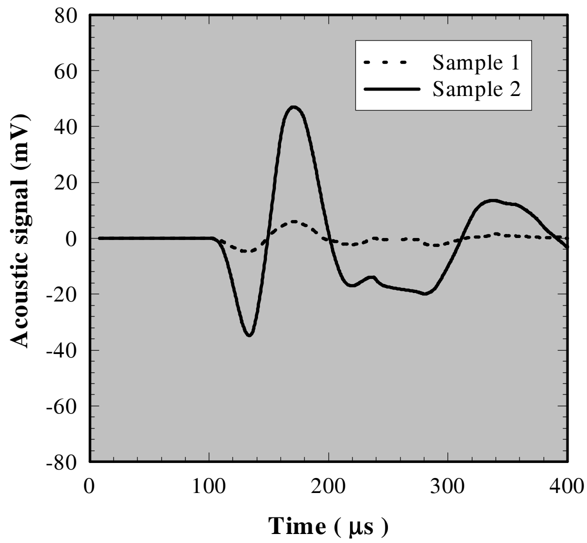

Fig. 2: Amplitude of the acoustic signals detected by the microphone, corresponding to the ablation of two surfaces with different amounts of dirt. The sample 1 is cleaner than the sample 2.

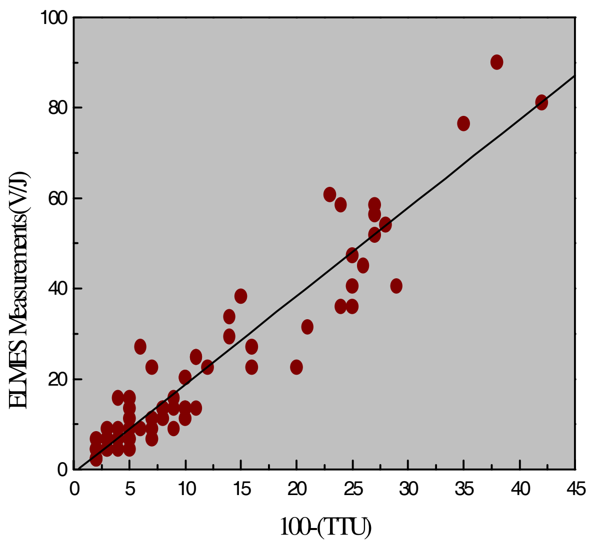

Fig. 3: Correlation between Tape method and ELMES measurements.TTU: Tape Transmission Units.

take place. One of them is the emission of a cracking sound whose intensity depends on the level of dirt. The sound intensity is detected by means of a microphone set at a fixed distance and angle with respect to the impact zone of the plate. A typical signal is shown in Fig. 2, and the peak-to-peak voltage is used as a measure of the amount of dirt.

Processing electronics allows the Fourier filtering of the background noise and subsequent averaging of several shots in order to further increase the signal to noise ratio. The measurement is performed on the moving plate so that successive laser shots impinge at different spots of the plate which are partially cleaned by the dirt ablation.

The calibration of the technique was made by cross checking plate samples with the adhesive tape method measured in *T*ape *T*ransmission *U*nits (TTU). The correlation obtained is shown in fig. 3.

III. CHARACTERISTICS OF THE ELMES

Based on the acoustic method developed and on the results obtained at the laboratory, the first industrial prototype of an instrument, named ELMES I ("EQUIPO LASER PARA MEDICION DE SUCIEDAD") was built (Bilmes and Martínez, 2000). The system was mounted at the Final Inspection Line (LIF in Spanish) of the Ensenada plant of the company SIDERAR).

The equipment follows the schematic of fig. 1, and a picture of the working system is shown in fig. 4. It consists of a pulsed Nd-YAG infrared laser, (wavelength: 1064 nm, pulsewidth: 20 ns, repetition rate: 3 Hz, beam diameter: 5 mm, pulse fluence: 0.2 J/ cm^2).

The laser head is included in a box that also encloses the detection electronics, and the energy meter used to monitor the laser. The microphone is installed in the excitement and detection module. The obtained signals are filtered, amplified and subsequently processed in a personal computer. The computer plots the average and dispersion of the measured dirt along the coil. The operator decides the number of shots that are used to determine each point in the graph. A standard sample is used to provide the calibration constants in order to match all similar equipment conditions.

In fig. 5 the measured residual dirt as a function of the laser shot number is plotted for two situations:
The first zone corresponds to the case in which the steel

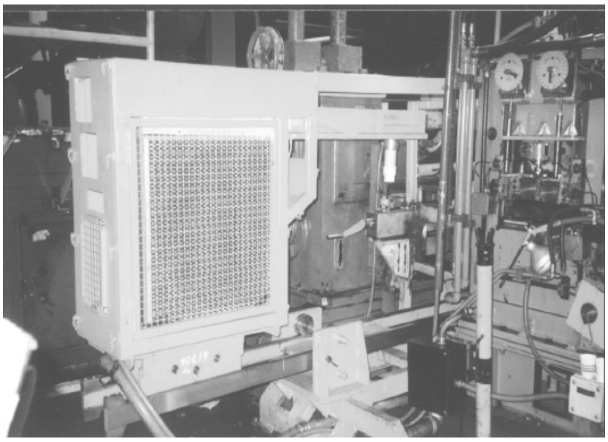

Fig. 4: Picture of the ELMES I installed at the Final Inspection Line of the Ensenada plant of SIDERAR.

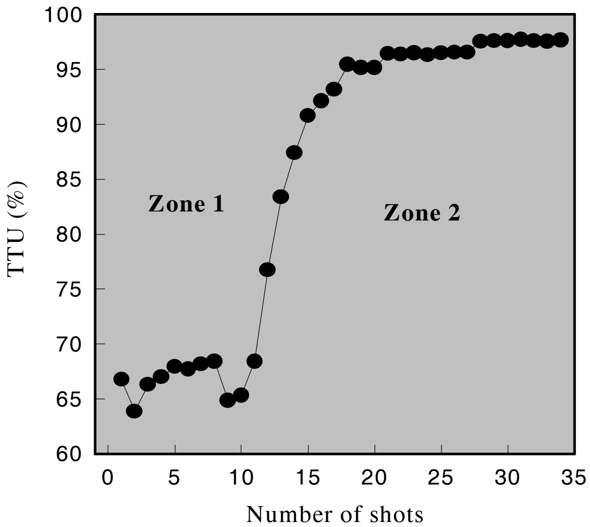

Fig. 5: Determination of the dirt in a steel foil. Zone 1:moving plate. Zone 2:stationary plate.

sheet is moving, so that successive shots impinge on different sites. The fluctuations in the signal can be attributed to the dispersion in the dirt concentration along the surface (about 50cm are scanned). The second zone shows the results when the steel sheet is stationary. All shots impact on the same spot, and the measured cleanliness grows as the dirt is ablated by the successive shots.

IV ILLUSTRATIVE EXAMPLES OF ONLINE MEASUREMENTS WITH THE ELMES I.

With the instrument ELMES I on-line it was possible to obtain complete profiles of dirt of the cold-rolled steel coils at the Ensenada plant of SIDERAR for the first time. The Figs.s 6, 7, 8 and 9 show some typical results.

Figure 6 corresponds to the measurement of a reference sample used as a standard for calibration. It also allows the determination of the fluctuations arising from the instrument itself, setting the precision of the measurement.

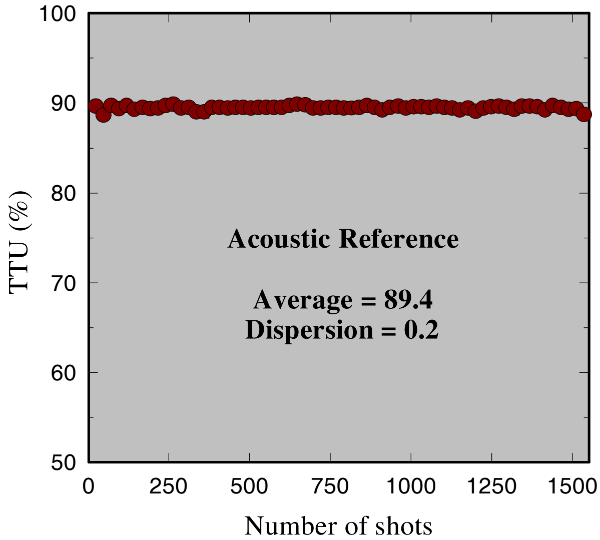

Fig. 6: Measure of the acoustic reference. Each point in the graph corresponds to an average of 24 shots. All the shots impact the same spot of the standard sample, showing that successive shots do not alter the surface.

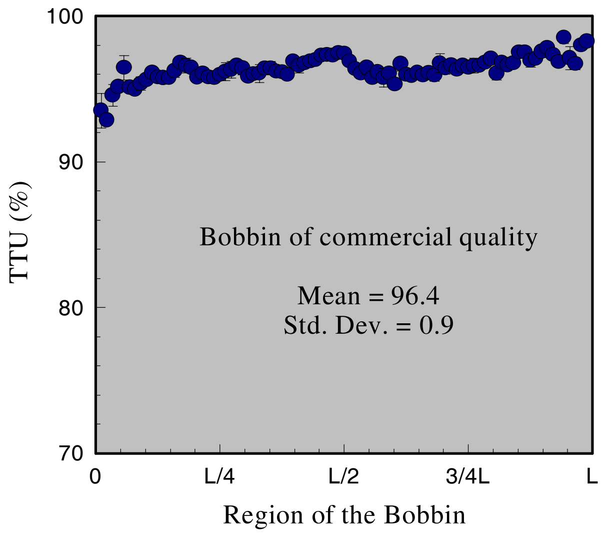

Fig. 7: Measurement obtained with a coil of commercial quality. It indicates that the degree of cleanliness is high and that the residual dirt is homogeneous along all its length.

Figure 7 shows the plot obtained for a typical measurement carried out in a standard coil of commercial quality.

Figure 8 corresponds to an oiled coil where the dirt is located only on the central part. This kind of problem cannot be detected by conventional methods based on samples taken at the coil ends.

Figure 9 shows a coil with an abnormal amount of dirt (below 70% equivalent transmission) in a substantial portion of its length. Since each measurement represents an average of 24 impacts of the laser in a region of 10 m of the foil, the error bars correspond to the dispersion of the dirt in each one of those areas. This type of

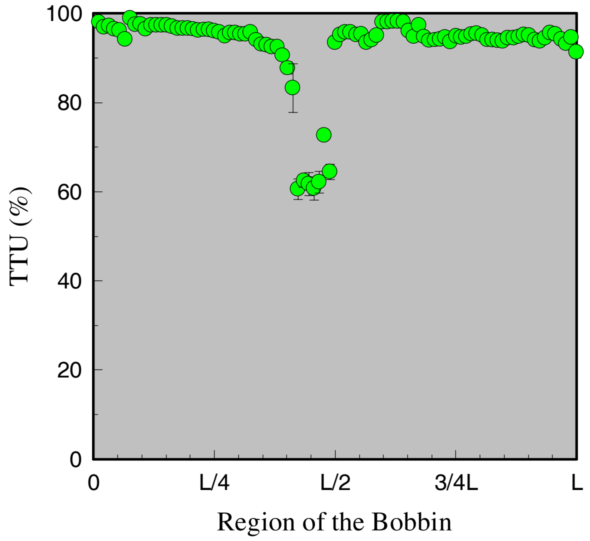

Fig. 8: Measurement corresponding to an oiled coil showing a central region with significant dirt.

determination allows an immediate upstream control and correction of the operations involved in the rolling process. This information was not accessible before the development of this new technique.

V. CONCLUSIONS

A method has been presented for the determination of surface cleanliness, that overcomes the most important drawbacks of the usual methods used in the steel industry:

1-. The measurement can be performed online, in real time, allowing the immediate correction of processing parameters that give rise to inadequate cleanliness of the material. The production line is not required to stop in order to take the sample.

2-. The method is automatic, avoiding uncertainties and errors arising from the manual operation required in other methods.

3-. The entire coil can be tested, and not selected portions where the sample is taken. In this manner it could be shown that the distribution of residual dirt is not homogeneous along the coil.

Due to the speed of the technique, multiple measurements allow the determination not only of the average dirt but also its standard deviation.

The correlation with the adhesive tape test was shown to be large, and due to the use of a calibration standard, the results of the measurement can be presented in units of equivalent transparency of the tape test.

The application shown was that of cold rolled steel plates, but the method should be useful for any other technological application requiring the determination of the surface cleanliness.

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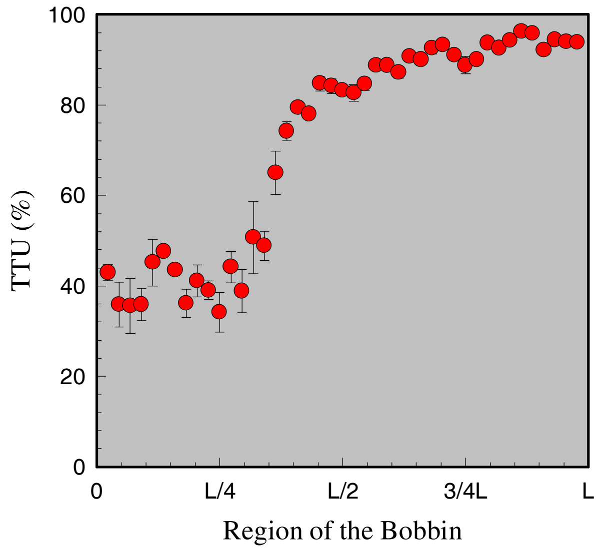

Fig. 9: Measurement corresponding to a coil with two regions of very different cleanliness. Notice that not only the first part is dirtier, but also the dispersion of the dirt is higher.

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