New tool for on-line diagnosis of thickness defects in tinplate*

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A new on-line guidance tool has been developed to help the mill operator with the achievement of a thickness performance that meets the ever more stringent requirements for DWI material.

The tool makes it possible to analyze the causes of thickness defects that are originated by the HSM or by the tandem mill.

* *Subject of a presentation at the 2004 ATS International Steelmaking Conference (Paris, December 9-10, 2004, Session 11).*

■ INTRODUCTION

The requested thickness of tinplate DWI is ever decreased : The requested nominal thickness was brought from 0.27 down to 0.23 mm in the 1995-2003 period. Further stringent constraints have been introduced recently.

Actions taken to meet the customer demand are presented in this paper, along with a new guidance tool that has been designed to facilitate the processing of DWI sheets.

Difficulties related to sheet thickness appear in the customer facilities. A can body maker is a highly productive forming tools with an output of six cans per second (1). The main defects, that may interfere with the can body maker operation, are small holes and wrinkles in the can wall.

Figure 1 shows a diagram of a can body maker :

– rounded blanks, 150 mm in diameter, are stamped from the DWI steel coil ;
– first cups are drawn, from the blanks ;
– the cups are then fed into an ironing press where successive rings redraw and iron them. This reduces the sidewall thickness, producing a full-length can ;
– the bottom of the can is shaped in a dome former ;
– finally it is discharged into a narrow hole adjustment machine.

At this stage of operation, two different types of defects may appear :

– the can may be too long, due to over-thickness of the blank ;
– the so-called "earing" defect, when the height is at great variance around the can.

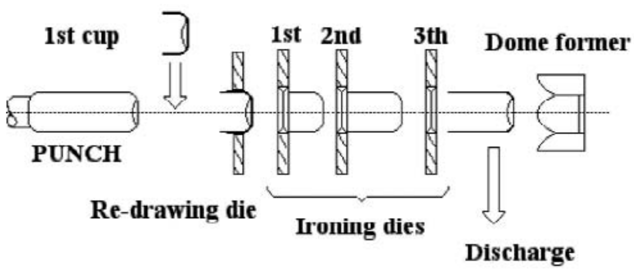

Fig. 1 – Scheme of a can body-maker.

Fig. 1 – Principe d'une machine de formage de boîte-boisson.

Nouveau diagnostic en ligne des défauts d'épaisseur du fer-blanc

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L'épaisseur du fer-blanc DWI pour boîte-boisson est actuellement de 0,23 mm et elle diminue régulièrement depuis de nombreuses années. La principale difficulté rencontrée lors du formage du corps de la boîte-boisson par emboutissage et repassage est liée à la présence éventuelle de cornes d'emboutissage qui gênent l'éjection de la boîte hors du « body-maker » en fin de formage.

Les études préliminaires ont établi que ce problème est lié à une épaisseur irrégulière du flanc d'emboutissage, donc à des variations d'épaisseur de la bande à une échelle de l'ordre de 150 mm environ. Ces défauts peuvent effectivement être détectés par mesures d'épaisseur X de la bande en défilement lent.

Un outil de pilotage a donc été développé pour aider l'opérateur à obtenir une qualité de laminage qui réponde aux besoins réels de l'utilisateur du DWI. Le système, fondé sur un nouvel algorithme avec les logiciels et matériels adaptés, permet l'évaluation en ligne de l'aptitude à l'emploi de la bande en cours de laminage.

Le système fournit de nombreuses informations complémentaires. Il permet de détecter des cylindres défectueux au TAB ou au tandem. ll peut mettre en évidence l'effet sur l'épaisseur d'un refroidissement inadapté dans une cage.

Le système est aussi capable d'identifier les défauts d'épaisseur au TAB et leurs répercussions possibles sur les épaisseurs au tandem. Il s'agit le plus souvent de la conséquence de l'excentricité des cylindres. Cela permet en particulier de changer les cylindres d'appui avant qu'il ne soit nécessaire de déclasser le produit.

Les résultats obtenus à Avilès ont motivé l'installation de deux systèmes identiques sur les laminoirs d'Etxebarri.

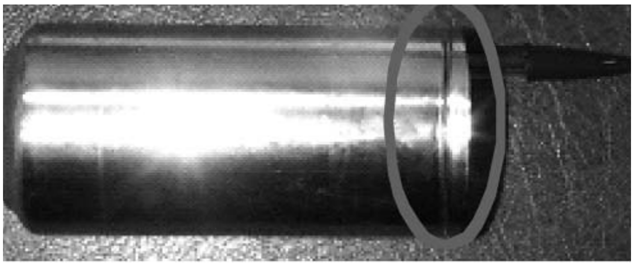

Fig. 2 – Wrinkle produced by stripper fingers when extracting cans.

Fig. 2 – Pli formé par les extracteurs sur la boîte.

This paper addresses the second type of defect whose consequence on body maker operation is the following : when the can is extracted on retracting the punch by the stripper fingers, the can edge is not pushed uniformly and wrinkles appear that create troubles, such as jumps, in the body maker (*fig. 2*).

■ PRELIMINARY STUDIES

Initial studies were made to find out the actual causes of the defect. Several cups and strips from coils that had given troubles in the customer's facilities were measured in order to assess the influence of thickness of the strip on cup earing.

Figure 3 shows the relation between the unevenness of thickness measured at the bottom of the cup and the amount of earing observed on the can. Thickness variation was then investigated on the tin plate strip itself. *Figure 4* presents a 10 m long sheet sampled from a customer that has been measured manually, about 6 times every 100 mm. It confirms that thickness variations of the first cup bottom were already in the strip as well. It was then decided to investigate what originates this thickness defect, and the tandem mill was deliberately suspected.

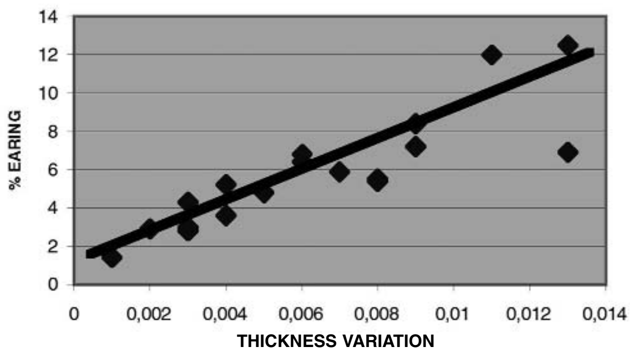

Fig. 3 – Earing as a function of thickness variation at the bottom of the cup.

Fig. 3 – Cornes en fonction de la dispersion d'épaisseur du fond de boîte.

Several coils coming from the tandem mill were processed through an inspection line at low speed (around 40 mpm) in order to detect any thickness variation.

Thickness variations were indeed detected in the strip (*fig. 5*) as they could be displayed by X-ray gauges at low speed.

It was thus decided to develop a new system to provide the operator with all necessary information on the coil being rolled, with reference to the customer requirements.

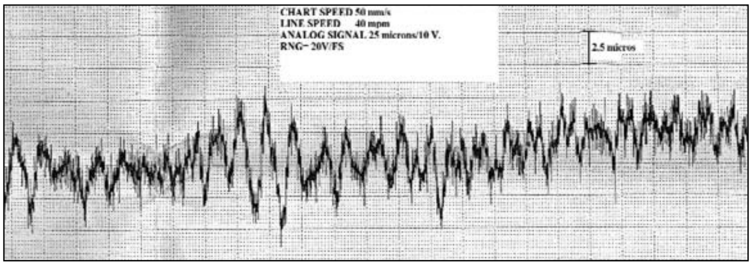

Fig. 5 – Thickness variation of the strip rolled on tandem mill, as detected by X-ray at low speed.

Fig. 5 – Variation d'épaisseur de la bande laminée au tandem, mesurée par rayons X en défilement lent.

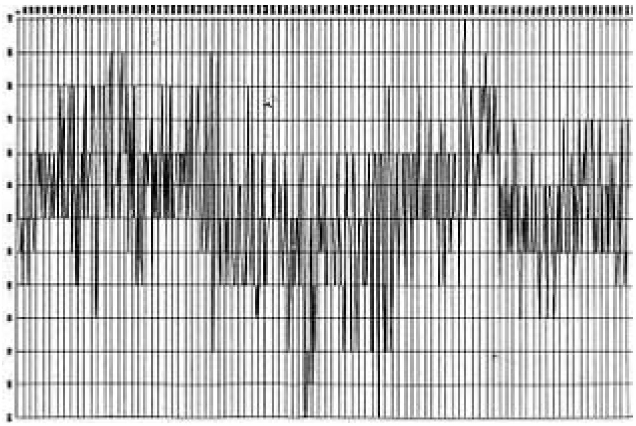

Fig. 4 – Thickness of a 9 m long strip (average of 6 manual measures every 100 mm).

Fig. 4 – Épaisseur d'une bande de 9 m de long (moyenne de 6 mesures manuelles tous les 100 mm).

■ X RAY POSSIBILITIES AND NEW HARDWARE DEVELOPMENT

Next step was to study X-ray gauges looking for a suitable signal of the strip condition at normal tandem mill rolling speed (1,500 mpm).

As the occurrence of the thickness defect is critical every 150 mm (diameter of the blank) and considering the low thickness of the sheet, the noise has to be filtered and a fast response is essential.

X-ray gauges detect thickness variations up to a maximum frequency. When the mill is running at high speed, the acquisition of thickness is smoothed due to behaviour of the gauge as a low-pass filter and due also to the spot width. The aim of the new equipment was to catch thickness variations in small portions along the strip which appear as frequencies higher than the gauge cut-off frequency when the mill is running at a normal speed ; thus becoming hidden from the gauge processing units.

Nevertheless, this high frequency component is still present at the input stages of the gauge, just before its processing section, but as the signal picked up by the X-ray sensor (phototube) has an exponential behaviour, it is not linear and a logarithmic adapter is needed for compensation. As a way out, a logarithmic isolator adapter has been designed : the signal is picked up from the first phototube amplifier after some notch filtering stages intended to remove two carrier frequencies generated by power sections of the gauge. The signal, which is continuous voltage (CC) contains deviation signal with some offset. It is connected to the low pass filter (*fig. 6*) that removes frequency components above 720 Hz, which is just noise. Its output feeds the logarithmic amplifier which is the heart of the system. As this stage relies on the characteristics of a diode, the output is quite low and needs amplifying. This task is done by the next amplifier stage raising the level of the processed signal. In order to keep the gauge circuit and the computer circuit electrically separated, an isolation stage is included. Finally to cope with long distance transmission, instead of providing the processed signal in voltage, a current converter has been designed. Some adjustments inside the board allow the response to be the most accurate and linear as possible.

As shown in *figure 7*, the adaptor is placed just between the input part of X-ray gauge and the computer that receives and processes the deviation signal.

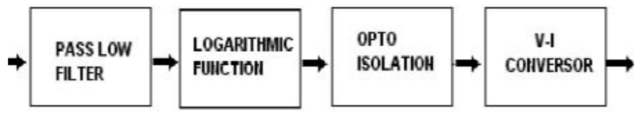

Fig. 6 – Logarithmic adapter block diagram.

Fig. 6 – Diagramme de l'adaptateur logarithmique.

Fig. 7 – Logarithmic adapter interconnection.

Fig. 7 – Interconnection de l'adaptateur logarithmique.

■ SOFTWARE DEVELOPED

The algorithm

The principle of on-line thickness evaluation was based on the previous experience of the Quality Department. The algorithm calculates the maximum variation of thickness detected along a longitudinal section of strip we call “coupon”.

For every coupon ‘k’ with a length of ‘C’ millimeters, a vector of ‘m’ samples of strip thickness is taken. We will call this vector of samples $\{X^k\}$, and the maximum difference is calculated as follows :

$$max\{|a-b|\},\quad a,b\in\{X_1^{\,k},\ldots,X_{m/2}^{\,k},X_{(m/2)+1}^{\,k-1},\ldots,X_m^{\,k-1}\}$$

or :

$$max(X)-min(X),\quad X=\{X_1^{\,k},\ldots,X_{m/2}^{\,k},X_{(m/2)+1}^{\,k-1},\ldots,X_m^{\,k-1}\}$$

Once this calculation is done, the result is stored and a displacement of m/2 is made. The calculation is then repeated with the new vector of samples.

In practice every time the strip advances C/2 millimeters, m/2 new samples have been taken and the maximum difference is searched then from new samples and m/2 last samples from the previous acquisition. This process is shown in *figure 8*. Every maximum difference is recorded in a vector {M} which is finally analyzed when a certain length L of the strip (for instance 20 or 30 meters) has been processed. The maximum value is, then, plotted on the screen. A percentage of values that have over-passed a determinate threshold U, based on the customer experience, is also displayed.

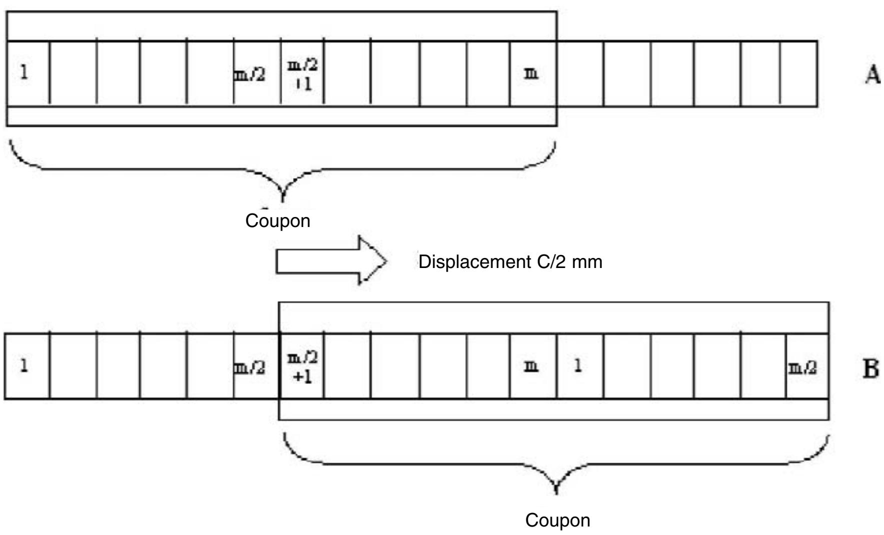

Fig. 8 – Algoritm representation.

Fig. 8 – Représentation de l’algorithme.

■ PROTOTYPE IMPLEMENTATION

The main targets for the final application are :

– monitoring of strip thickness ;

– thickness quality analysis, using the algorithm previously described ;

– relevant storage of the data for future query or analysis ;

– frequency analysis of the thickness data ;

– generation of quality reports.

A fully working prototype with these features was developed and was installed in the facility in a PC equipped with a data translation DT304 analog/digital card.

The design of the software application was prepared for future additions of new algorithms or functions as well as changes in the system environment, new I/O hardware or installation needs. Thus the modularity is of key importance. To achieve this, identifying the modules that compose the application is essential. These modules are :

– Input/Output module. This module should permit introducing different data acquisition cards when needed ;

– Printing module. In charge of printing different kinds of report based on particular requirements ;

– Data Processing module. This module makes it possible to introduce different algorithms without modifying the existing software, just installing new components ;

– User Interface module. Representation of different types of plots with the required data ;

– Database module. Possibility of using different database engines. Also different user interfaces are easily created without the need of huge software modifications ;

– Communication module. It implements and isolates the communication protocol with other systems for information exchange, making it easy to adapt the application to different environments and installations.

The application architecture was finally designed as seen in *figure 9* where a new module called Data Server is added. This new module keeps track of all data that are either acquired or calculated by the system, and implements a hotlink system, so other modules may be informed of data modifications. Each module may request the creation of a new variable in the Data Server, subscribe to any variable or modify their value with a common easy-to-use general-purpose interface.

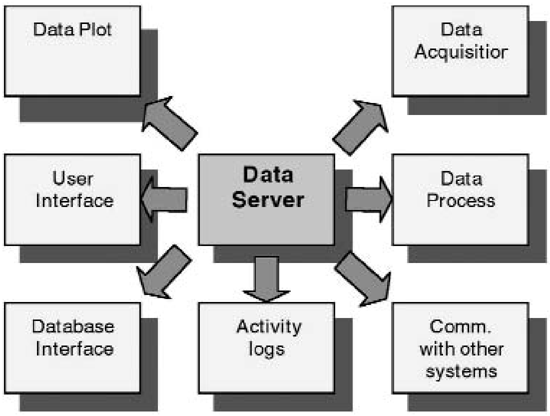

Fig. 9 – Representation of modular software development.

Fig. 9 – Représentation des modules du logiciel.

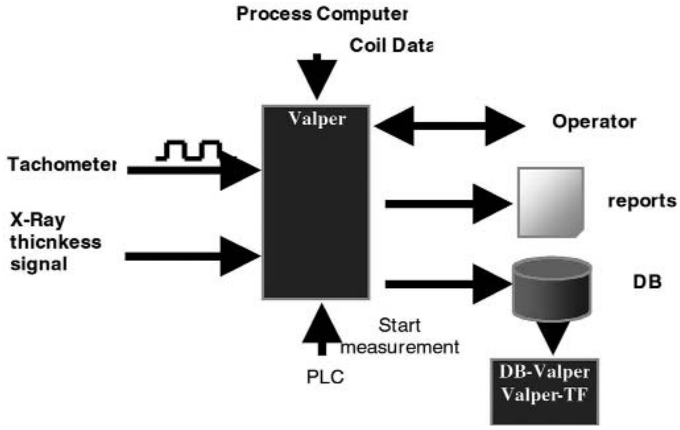

Fig. 10 – Equipment implementation scheme.

Fig. 10 – Principe de mise en œuvre du système.

■ FACILITY LAYOUT

Figure 10 shows the general block description of the application. A tachometer attached to the mill displays both the information of instantaneous speed and longitudinal displacement of the strip. A digital signal from the PLC indicates when the system should start processing. All the additional data needed are provided by the process computer through a communication protocol.

Operator interface screen

The interface screen is shown in *figure 11*. The system has the possibility to display different signals (thickness, speed, thickness quality, etc.) under operator requirement. The user interface allows the possibility of accepting process data introduced by the operator, even if this data usually comes from the process computer, using a pre-defined communication protocol. This approach allows continuous working, even if a communication failure occurs. Other useful information is displayed on the main screen, such as the system status, working speed, strip data and processed length. The way of working on-line is also shown in this figure. The algorithm is evaluated on-line and its result is plotted on the main screen. Helped by threshold level, previously adjusted (straight line sited on the plot), the operator is able to see if a coil is fit for the customer. In the present example, the coil that is being rolled satisfies the requirement of the customer.

■ SOME EXAMPLES OF RESULTS

The main results can be divided in two different areas : the metallurgical study of a detected defect explained at the beginning of this paper and the development and exploitation of the tool developed for on-line monitoring of the quality required by customers.

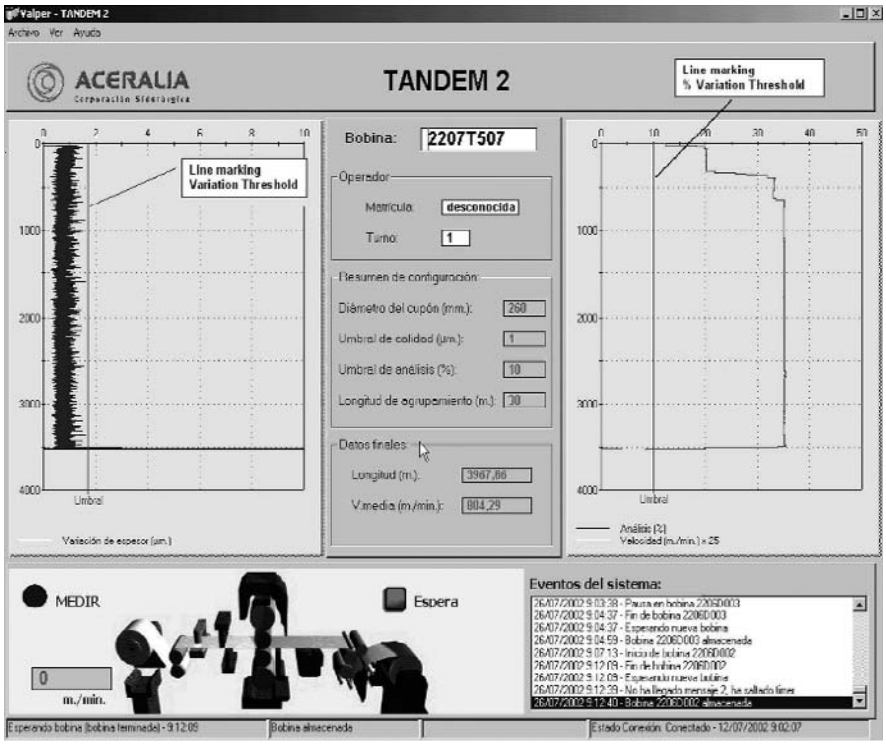

Fig. 11 – Screen display with threshold lines.

Fig. 11 – Vue d'écran avec des valeurs limites.

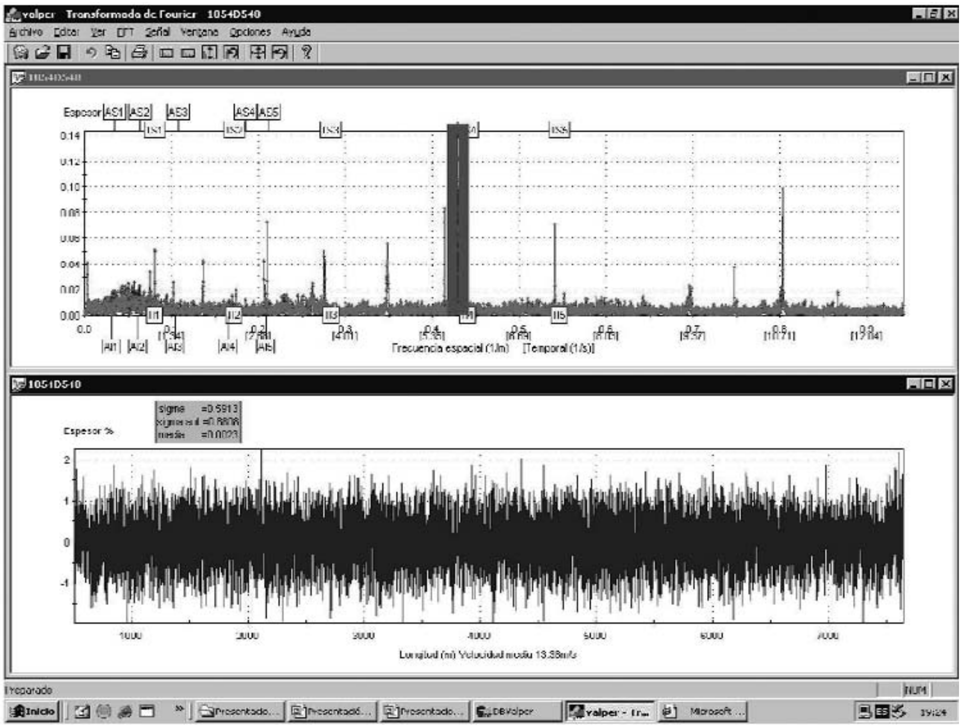

Fig. 12 – X-ray signal and its FFT with a frequency selected to be removed.

Fig. 12 – Signal X et transformée de Fourier, avec une fréquence à extraire.

Improving standard performance for customer

For DWI it is of prime importance to consider thickness variations along small portions of the strip. In fact, this is a more critical constraint than the global tolerance itself. Body makers accommodate blanks whose thickness is a little above tolerance to produce cans with a longer body that can be compensated for upon trimming. Body-makers may be jammed by blanks, with uneven thickness at short range, that generates holes and wrinkles. The on-line guidance-tool has been developed for helping with this problem. Indeed it makes it possible to identify some defects.

Detecting defective rolls

The tool that has been developed makes it possible to detect defective rolls, with an appropriate procedure. A study of influence of different harmonics to the signal of X-Ray can be done once the coil to be studied has been selected and its FFT is displayed on the screen (*fig. 12*). The small boxes are a scale based on roll diameter that means possible frequency of rotation.

X-axes of frequency are presented in m^{-1} and s^{-1} (Hertz). With this feature, the tool is able to avoid, by sampling constant space instead of constant time, the effect of any speed change on frequencies. In *figure 12*, the frequency to study is selected to be removed and to calculate its inverse FFT. *Figure 13* shows the effects over thickness after removing that frequency. It is clear that thickness presents less amplitude, 18.33 % of standard deviation has been reduced. This can give an idea that this harmonic with that amplitude has a lot of influence over the final strip thickness.

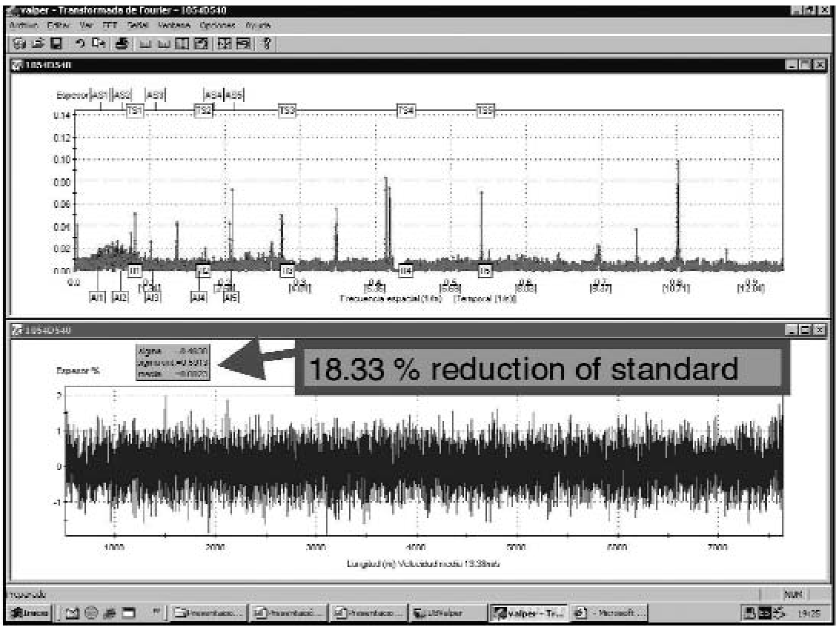

Fig. 13 – Thickness signal after the frequency to be studied has been removed.

Fig. 13 – Signal d'épaisseur après extraction de la fréquence à étudier.

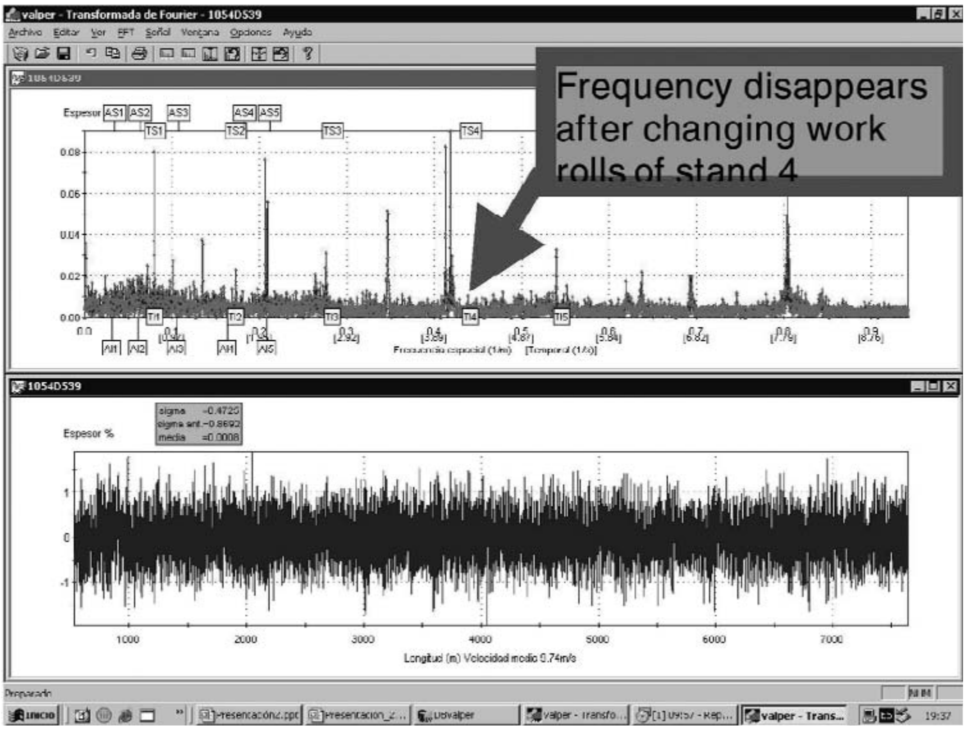

Fig. 14 – Thickness signal after changing rolls of stand 4.

Fig. 14 – Signal d'épaisseur après remplacement des cylindres de la cage 4.

In our case, just changing rolls brought a significant improvement. After removing the work rolls of stand 4, as previously foreseen, it can be seen how this frequency disappears (*fig. 14*) and ripple of thickness is less than on the previous coil. This demonstrates that the system is able to detect which stand is down grading the performance of the mill. Because the magnitude of changes cannot be appreciated easily, a direct calculation of standard deviation, before and after removing the harmonic, is shown on the screen.

Possibility to study 3rd octave frequencies

Another important feature of the equipment is the possibility to study frequencies till 3rd octave (2, 3). By adjustment on the configuration screen, it is possible to acquire samples every 28 mm or even less, allowing to obtain the spectrum up to a maximum frequency on the order of 300 Hz. It is clear that this maximum value of frequency depends on rolling speed and sample rate. As FFT is calculated off-line from data taken from the database, the real sampling rate for FFT is the storing rate (number of mm at which a thickness value is stored).

In *figure 15*, a chatter vibration occurs in the mill and it is detected on-line for the guidance-tool. On the left side, the thickness variation signal clearly oversteps the fixed threshold while the right side shows how the mill decelerates as its chatter protection system is activated to avoid strip breakage. The signal of thickness variation clearly shows that the effect on the strip is very located. After deceleration, as soon as stability is recovered, the mill accelerates again.

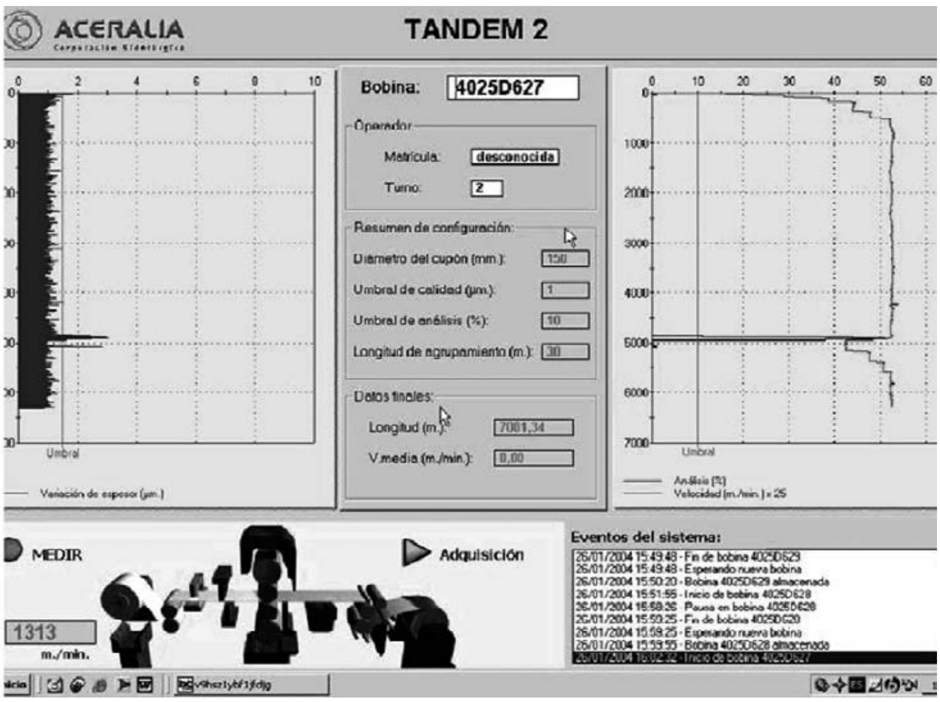

Fig. 15 – Screenshot showing chatter vibration.

Fig. 15 – Enregistrement caractéristique du broutage.

Data storing on this coil was quick enough to allow us to obtain a maximum spatial frequency of about 9.6 m^{-1}.

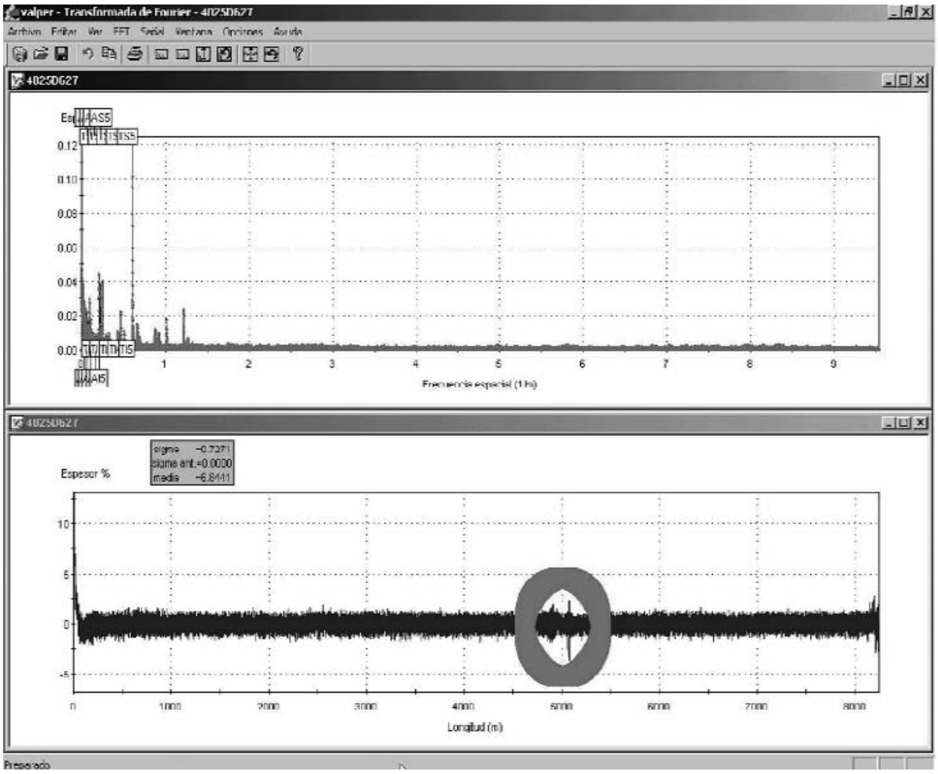

Fig. 16 – Screenshot showing initial signal associated with chatter.

Fig. 16 – Signal enregistré à l'origine du broutage.

Considering the circled area (*fig. 16*) where chatter occurs, the critical frequencies for this phenomenon have been determined (*fig. 17*).

Considering a strip speed of 1,313 mpm, the chatter frequencies of 173.5 and 181.8 Hz are obtained. These values are very close to the data from accelerators on the mill, with an error of less than 7 Hz that may be accounted for by the actual value of strip speed.

Another important factor with FFT is that the amplitude of frequencies obtained depends on how long the harmonic considered is present in the signal. FFT shows the whole harmonics but does not give any information about time. Combining direct and inverse FFT, it is possible to obtain some temporal information but it means that the importance of the final signal is not directly related to the amplitude obtained. This system cannot analyze higher frequencies as X-ray act then as a filter.

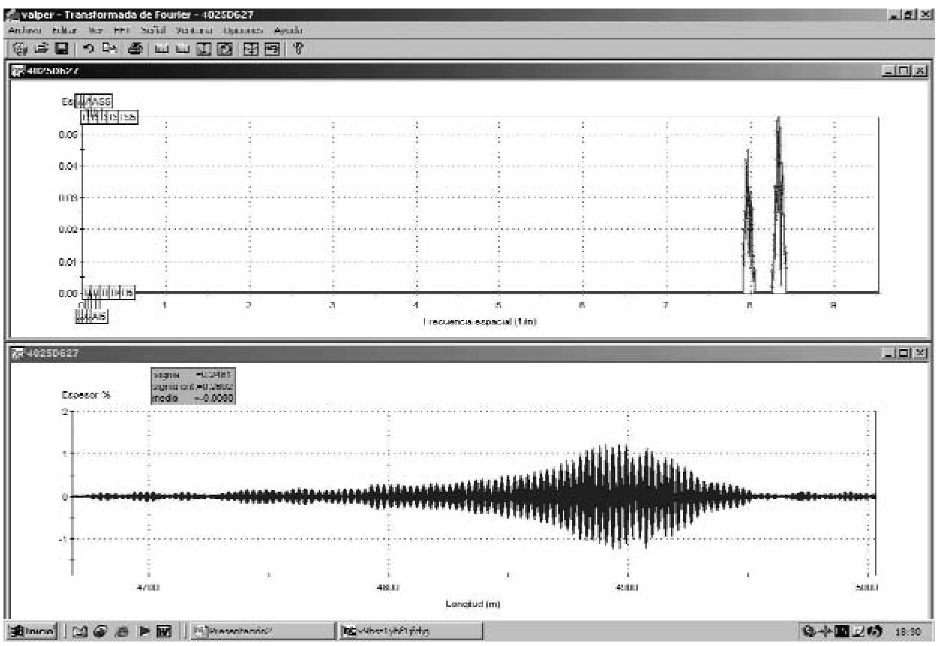

Fig. 17 – Screenshot showing chatter frequencies.

Fig. 17 – Mise en évidence des fréquences de broutage.

Coolant effect on frequency

The tool makes it possible to detect unsuspected defects on the mill. In *figure 18* thickness performance shows two parts : part B has a lower ripple than part A. Such a difference may be significant for strips with a tight thickness tolerance, as DWI for example. The two different zones have been studied independently. The tool can calculate separately FFT from part A and B. *Figure 19* shows that some increment in the frequencies in the proximity of 0.08 m^{-1} is detected in section A. For part B (*fig. 20*) with a lower ripple, the same calculation shows a much lower amplitude for these frequencies.

After several trials, a clear relationship has been established between strip temperature at mill exit and the variation of the thickness ripple. *Figure 21* shows the profile of temperature extracted from a thermograph scan sited at mill exit. Thickness variation occurs when a decrement of temperature is produced.

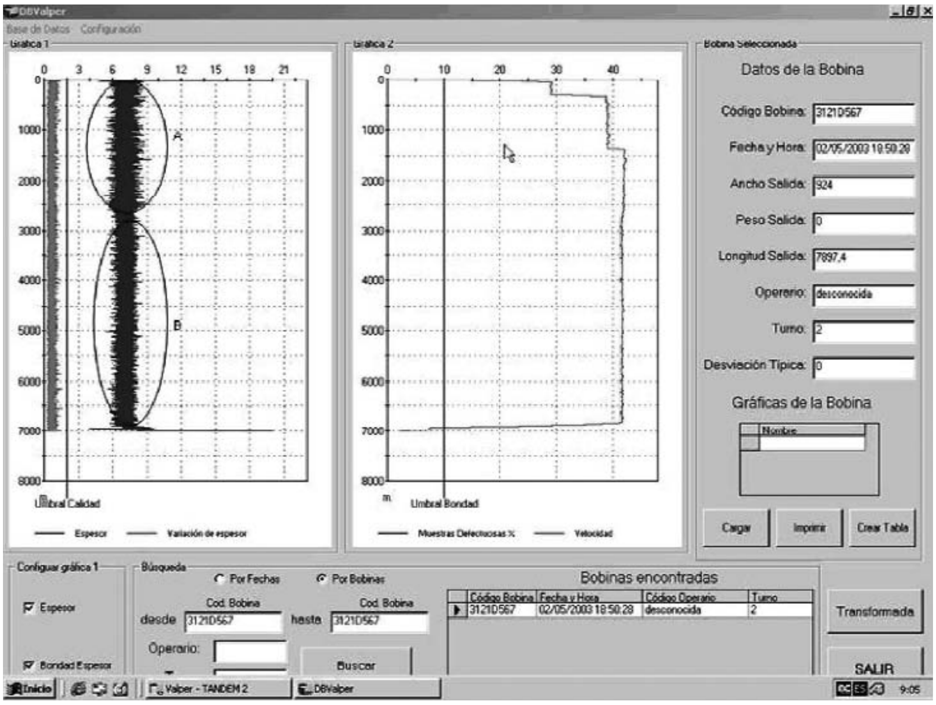

Fig. 18 – Two different ripples of thickness.

Fig. 18 – Deux ondulations d'épaisseur.

Eventually, the phenomenon has been ascribed to a coolant modification at stand 4. *Figure 21* shows that an increased flow of coolant at stand 4 decreases the exit temperature, as it is recorded by pyrometer and thermograph plots. This decrease of the exit temperature fits with thickness modifications. New rules have thus been introduced about the use of coolant when rolling critical materials.

Inter-facilities defects detected

The aim is to establish correlations between delivery thickness at the HSM and at the tandem mill. *Figure 22* shows a thickness defect detected at exit of stand 1 of the tandem mill. At the mill delivery, some peaks in the signal reveal an abnormal variation of thickness that is mostly inside ± 2 %. Such peaks in a critical material could have the coil rejected. Investigating the HSM for the origin of trouble, data extracted from the database establish that the back up rolls of stand 4 and 6 are defective (*fig. 23*). A campaign of study was thus started. Several observations demonstrated that after cobbles or strip breakages, the eccentricity of rolls can be modified. The research demonstrated that rolls that have been changed recently can have high amplitude of related harmonics in FFT, even after rolling a few coils only and that they must be changed. After many trials, the conclusion was that rolls in the mill must have less than 20 tons of eccentricity to afford the best rolling condition.

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■ CONCLUSIONS

Several complementary fields of research have been addressed. First the effect of DWI material on the performance of extraction from a can body-maker was investigated. The "earing" phenomenon was ascribed to short range thickness variations of the DWI material. This new parameter must then be considered as significant as the global thickness tole-

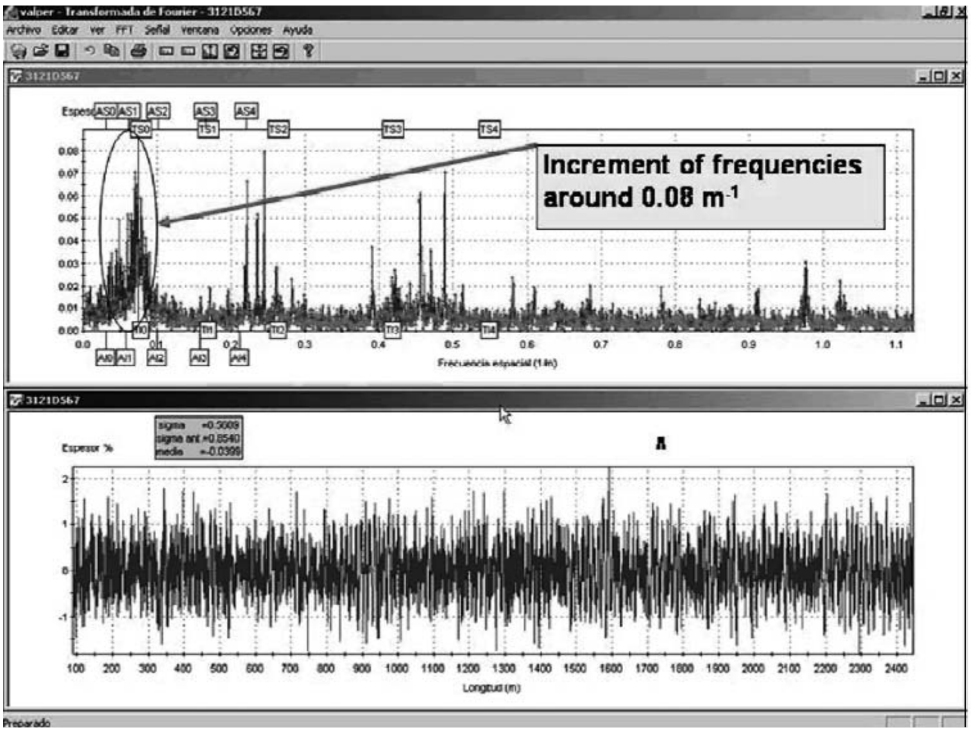

Fig. 19 – Increments of frequencies around 0.08 m^{-1} (zone A of fig. 18).

Fig. 19 – Incréments de fréquence de l'ordre de 0,08 m^{-1} (zone A de la fig. 18).

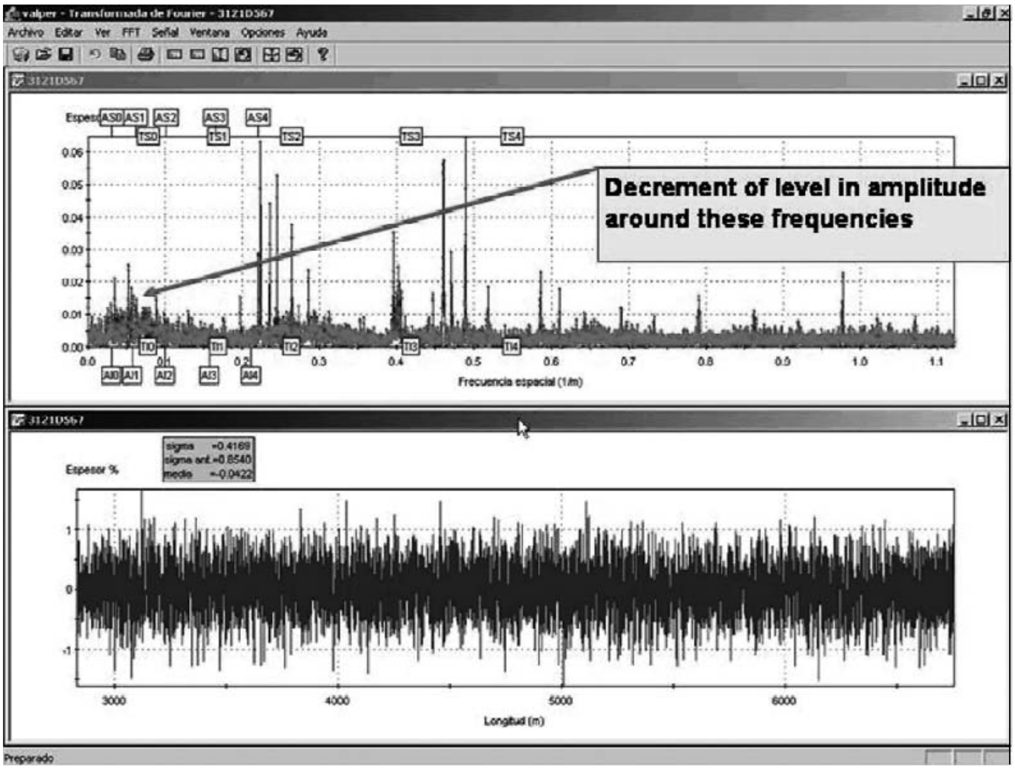

Fig. 20 – Decrement of frequencies around 0.08 m^{-1} (zone B of fig. 18).

Fig. 20 – Décrément de fréquence de l'ordre de 0,08 m^{-1} (zone B de la fig. 18).

rance when assessing the quality of the DWI material. Although the specifications of the customer are satisfied along the coil, problems may appear if a sudden thickness variation of the coil occurs within a short range (about 150 mm). Indeed a short ranged thickness variation is most critical for a body maker blank.

Thus, a guidance-tool has been developed to help the mill operator to achieve a performance of rolling that satisfies the customer needs. A new algorithm was created and the necessary hardware and software have been developed and implemented. Upon rolling, the new system is able to indicate on-line whether the coil fits the customer requirements.

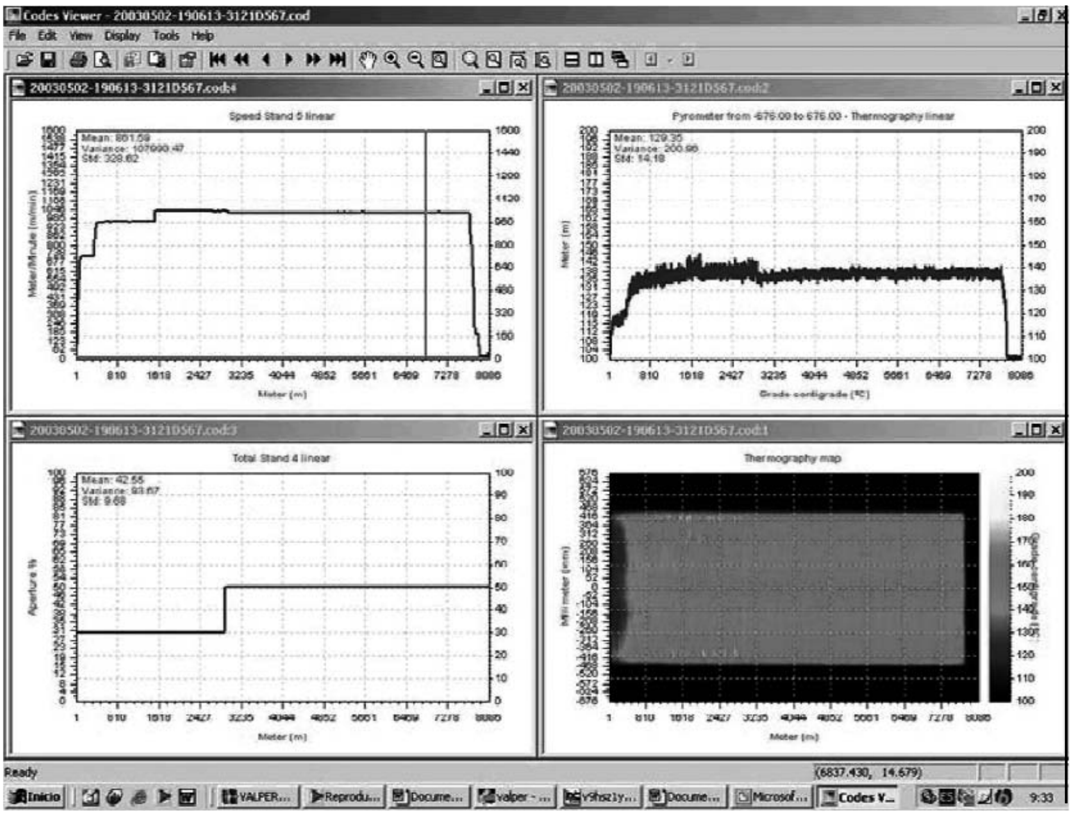

Fig. 21 – Plot of speed, strip exit temperature profile, coolant stand 4 and exit thermography.

Fig. 21 – Vitesse de la bande, température de sortie, arrosage à la cage 4 et thermographie de sortie.

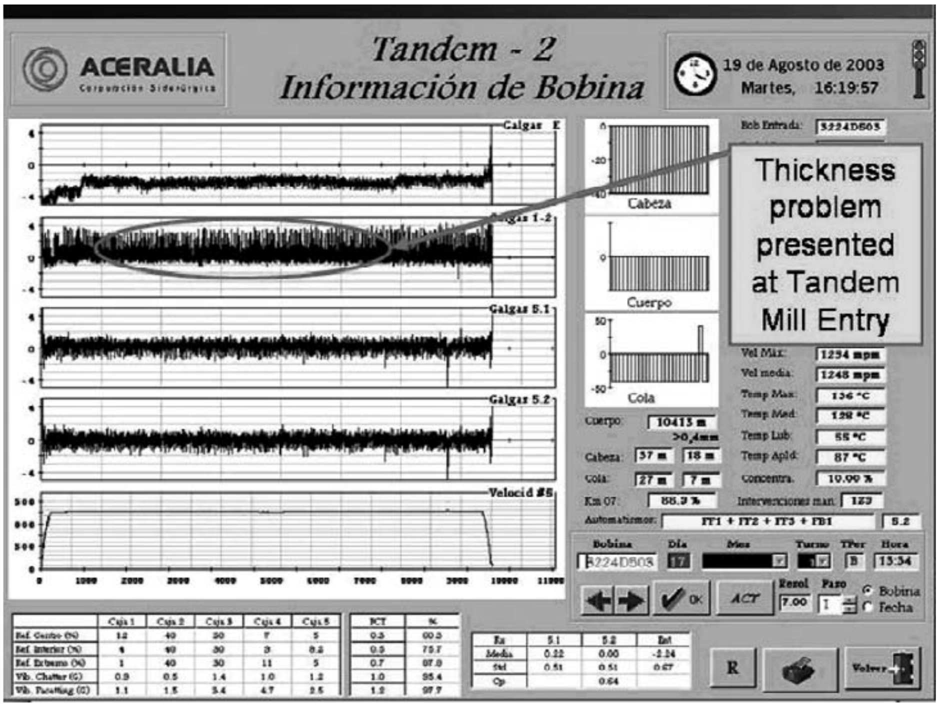

Fig. 22 – Display of thickness defect at exit of stand 1 of tandem mill.

Fig. 22 – Défaut d'épaisseur détecté à la sortie de la cage 1 du tandem.

and the rolling procedure of the tandem mill was modified accordingly.

The system proved useful to identify thickness defects from HSM and their possible consequence on thickness obtained in the tandem mill. Most defects are originated by roll eccentricity. Indeed roll eccentricity evolves through a rolling campaign, even with few coils rolled. The system makes it possible to follow and prevent any detrimental effect of over eccentricity. Especially, defective back up rolls can be changed before they cause the rejection of the material.

Considering the satisfactory performance of the equipments installed on the Avilés mill, similar equipments were implemented on two other reversing mills of Aceralia in Etxebarri (Vizcaya).

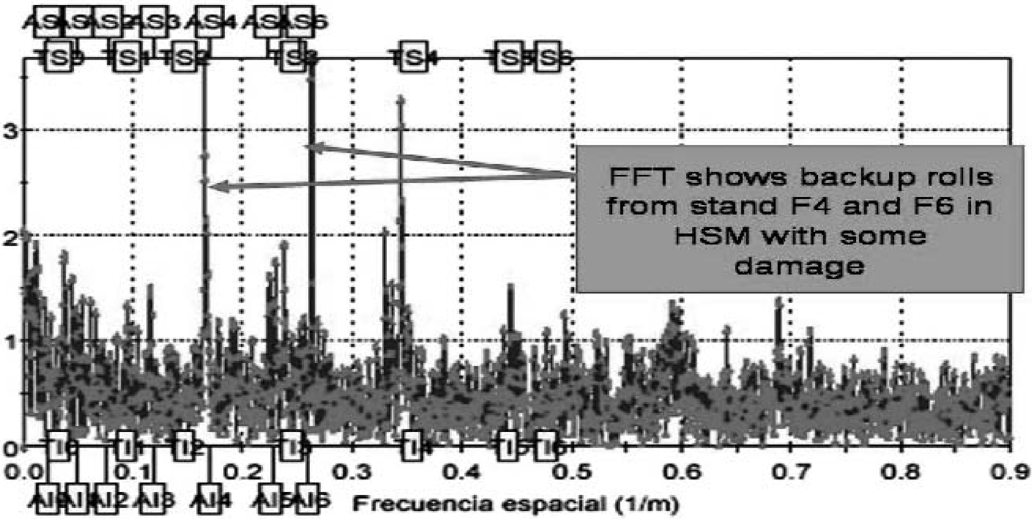

Fig. 23 – Defective back up rolls on HSM stands 4 and 6 as detected by FFT.

Fig. 23 – Cylindres d'appui défectueux aux cages 4 et 6 du TAB, détectés par les transformées de Fourier.

Associated with this tool, new features were installed and developed. These features can also be used without stopping the on-line surveillance application. Direct and inverse FFT has become very useful to analyze the causes of any final thickness defect. They do not loose the time information, unlike classical FFT that do suffer this drawback.

This made it possible to establish the detrimental effect of defective rolls on thickness in the HSM and in the tandem mill. It also proved useful to analyze several problems related with the exploitation of the mill. The influence of coolant at stand 4 on thickness was detected in this research

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