CHATTER DETECTION ON A TANDEM COLD MILL*

Danilo Gonçalves de Oliveira[1]
Rogério Martins Pereira[2]
Charles Pierri de Souza[3]
Bruno Bueckmann Diegoli[4]
José Vitor Librelato[5]

Abstract
Chatter is a widely studied vibration phenomenon that affects most cold mills around the world and its impact on these lines are tremendous: from productivity and quality losses to mechanical equipment damage. The investigation of its origins and how to minimize the occurrences and their impact on the equipment require special instrumentation and algorithms in order to have a detection of the vibrations as soon as they start. This paper presents three methods of identification of chatter on a Tandem Cold Mill and the actions to leave the vibration frequency range before its amplitude achieve catastrophic values.
Keywords: Cold rolling; Tandem cold mill; chatter detection; vibration.

[1] *Electrical Engineer, Research and Development Engineer, Global R&D - Brazil, ArcelorMittal Vega, São Francisco do Sul, Santa Catarina, Brazil.*
[2] *Electrical Engineer Msc, Reliability Specialist, PLTCM, BAF and SPM Production Department, ArcelorMittal Vega, São Francisco do Sul, Santa Catarina, Brazil.*
[3] *Technologist in Production Management, Production Process Specialist, PLTCM Production Department, ArcelorMittal Vega, São Francisco do Sul, Santa Catarina, Brazil.*
[4] *Automation Engineer, Automation Engineer, PLTCM, BAF and SPM Production Department, ArcelorMittal Vega, São Francisco do Sul, Santa Catarina, Brazil.*
[5] *Mechanical Engineer, Maintenance and Asset Management Specialist, Performance Excellence Department, ArcelorMittal Vega, São Francisco do Sul, Santa Catarina, Brazil.*

1 Introduction

Chatter is one of the main problems in the cold rolling of strip in tandem mills. Reduction in productivity due to chatter vibration has important effect on the price of rolled strips. Thus, it's not only an industrial problem, but also an economic concern in modern rolling mills [1]. Chatters are a particular case of self-excited vibrations which arise in rolling operations as a consequence of the interaction between the structural dynamics of the mill stand and the dynamics of the rolling operation itself [2] and its occurrences are a worldwide problem which affects different cold rolling mills (4-high, 6-high and 20-high) and products (steel, aluminum, etc) [2, 3, 4].
In the steel industry, the two main vibration modes are third-octave chatter (frequency ranging from 90 to 250Hz) and fifth-octave chatter (500 to 700Hz) [5].
Researchers pay great attention to the third-octave mode chatter because it leads to serious gauge fluctuation, and even mill structure damage [2]. It is due to self-excitation of one of the natural frequency components of mill stand due to changes in rolling condition like friction, emulsion heat dissipating properties, etc [6]. Under resonance mill vibrates violently, producing loud noises audible at great distances, with increasing amplitude leading to large periodic thickness gauge variation in the strip [6]. The severity of these vibrations increases with mill speed [6,7] and if mill speed is not decreased immediately vibration amplitude increases rapidly leading to catastrophic strip break. Sometimes it significantly hampers productivity of the mill by limiting the top speed [6] or by causing processing interruptions and equipment damage.
Fifth-octave vibrations are forced vibration in the frequency range of 600Hz to 1200Hz. It's due to resonance in mill stands excited from some external source. Chatter marks are generated on backup rolls and printed via work rolls on the surface of the strip with spacing between 10mm to 40 mm [6] resulting in significant losses related to quality downgrading. In contrast to the third-octave mode, the fifth-octave chatter does not produce audible noise nor strip breaks making it more difficult to be detected without the proper instrumentation.

Figure 1. Fifth-octave chatter marks on steel strip.

With the startup of the second hot dip galvanizing line (HDG#2) in 2010 at ArcelorMittal Vega (AMV), the Pickling Line and Tandem Cold Mill (PLTCM) has observed a significant change in the product mix.
Differently from the HDG#1, which focus on the automotive industry, this new HDG line was designed to target the white goods and construction markets. These segments have led to the introduction of thicknesses as low as 0.37mm into the PLTCM product mix, which was originally designed to roll down to 0.40mm but had little experience with strips below 0.50mm.

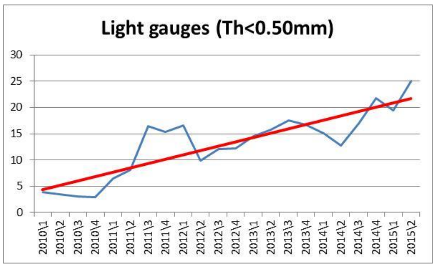

Figure 2. Percentage of the product mix composed of thickness<0.50mm.

Sporadic occurrences of third-octave chatter were reported prior to 2010, but only in 2011 they became more frequent

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but not yet enough to initiate a special contingency plan as the losses were still restricted to very low tonnage.

In mid-2012, however, an important quality crisis emerged: more than 1,100t of exposed materials have been downgraded. These losses were concentrated on automotive products and the defect was only detected after the galvanizing lines, which has significantly increased its impact on the company's financial figures. The defect consisted of fifth-octave chatter marks spaced approximately 40mm from each other which were later traced back to the backup rolls of stand #3.

This fifth-octave chatter quality crisis was also accompanied by a significant increase in the occurrences of the third-octave mode, which lead to additional quality losses related to thickness variations. These third-octave chatter events became even more critical when strip breaks at the galvanizing lines were linked to the thickness variations caused by mill stand vibrations.

Figure 3. Backup roll of stand3 with chatter marks.

A short-term contingency plan has been put in place to prevent further quality losses:

- Early change of backup rolls from 15 days to 7 days of operation;
- Periodic inspection of the full-hard coils at the Recoiling and Inspection Line (RIL) before campaigns of exposed products;
- Frequent visual inspection of backup rolls;

This action plan addressed the quality crisis in some extent but at a significant cost:

- Increased backup roll consumption;
- Additional operational procedures and quality inspections;
- Increased production costs with the rework of full-hard coils at RIL;

After the crisis, a thorough analysis of the events indicated that an automatic detection method was mandatory to prevent similar quality crisis in the future and eliminate the extra cost caused by the short-term action plan.

Soon after the definition of the short-term action plan, a team of engineers has been put together to identify the technologies (and their cost) currently available in the market for early chatter detection and prevention for the PLTCM.

The first steps consisted in a deep revision of the literature and contact was made with ArcelorMittal R&D and other ArcelorMittal mills in order to establish what's the state-of-the-art in chatter detection and prevention.

Keintzel at al. [7] proposes the installation of sophisticated servo-valves operating at chatter frequency to damp the vibrations and stabilize the system. This active chatter prevention is very interesting to avoid third-octave chatter but it's not yet suitable for fifth-octave mode, which was the main cause of the quality crisis in AMV.

Using much less sophisticated equipment, several mills around the globe rely on simple accelerometers mounted on the top of the mill stands to detect the vibrations and automatically decelerate the line for third-octave chatter or change backup rolls when fifth-octave frequency range is detected. Even though this is not an ideal situation as it doesn't address the root causes of the phenomenon, it's results from the quality point of view are significant with a comparably low investment.

The objective of this paper is to present the low-cost solutions applied to reduce the impacts of third-octave and fifth-octave chatter events. The identification of the different excitation sources and chatter root causes are not being discussed in this document.

2 Material and Methods

Every off-the-shelf solution identified by AMV engineers required some level of investment.
Several meetings were held with recog-nized suppliers, with the support of ArcelorMittal R&D, to define the best solution and the total investment required for its implementation.
As investment planning takes considerable time, in parallel to this, the team of engineers initiated in-house developments to reduce the risks of new chatter related quality crisis and potentially reduce the required investment.

2.1 Manual Intervention

The third-octave chatter mode produces loud audible noise and can be easily identified by line operators.
In normal operation, the line speed is manually set by the Operators utilizing the available pushbuttons of the control panel. The acceleration and deceleration ratios are usually low for the products prone to chatter occurrences (thickness lower than 0.50mm) and the time required to reduce the speed and leave the chatter speed range is typically too long (up to 15s depending on the line speed) and thus it's difficult for the line operator to hear the mill vibration, react and press the button to reduce line speed in time to prevent severe damage to the strip quality and equipment integrity.
Additionally, after decelerating the mill in a chatter event, the operator typically runs the rest of the coil in a lower speed in order to avoid additional events in the same product.
In order to aid the line operators in this difficult task, an emergency button has been installed in the control panel. When activated, it would double the deceleration ratio significantly improving the chances of success when the operator had to manually control the speed and reduce the mill vibration. Another feature of the chatter button is to reduce the line speed by a fixed 180mpm, which is sufficient to avoid the chatter speed range but much higher than what would be set by operators.
Obviously, this solution is far from ideal as it relies on the reaction of line operators to the noises produced by the vibrating stand. Nonetheless, it was a welcome improvement since it significantly improved the effectiveness of manual interventions of the operators.

2.2 Detection by Rolling Force

Third-octave chatter can be easily identified in the after-rolling inspection as it produces significant thickness distur-bances [1].
Figure 4 shows real thickness measure-ments at the exit side of the cold mill in a third-octave chatter event. As can be seen, the thickness, in this particular case, oscillates between +4 and -6%. But the thickness gauge communication with the line data acquisition system occurs at 20Hz, much lower than the chatter vibration (~120Hz). Manual measurements have indicated that the real thickness variation can be 5 to 6 times higher than what the thickness gauge reports.

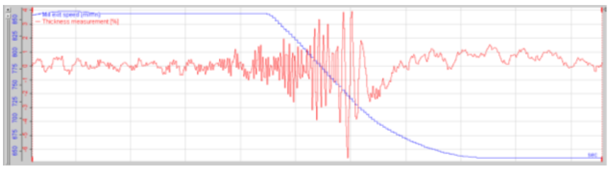

Figure 4. Real thickness measurement (red) on exit side of cold mill due to third-octave chatter.

This significant thickness variation gen-erated by the mill vibration reflects in other elements of the tandem mill and its effect can be seen, in example, on entry and delivered tensions of the vibrating stand. But one of the most affected variables is the rolling force, as shown in Figure 5.

As the mill stand vibrates, the induced thickness variations are a result of upper work roll vibrating in an opposite direction to that of the lower work roll [3]. This relative movement between the rolls changes the geometry of the roll bite [8] resulting in an oscillating change in the rolling force. This unusual variation can be detected by the pressure transducers installed in the hydraulic capsule on top of the backup rolls designed to measure the rolling force.

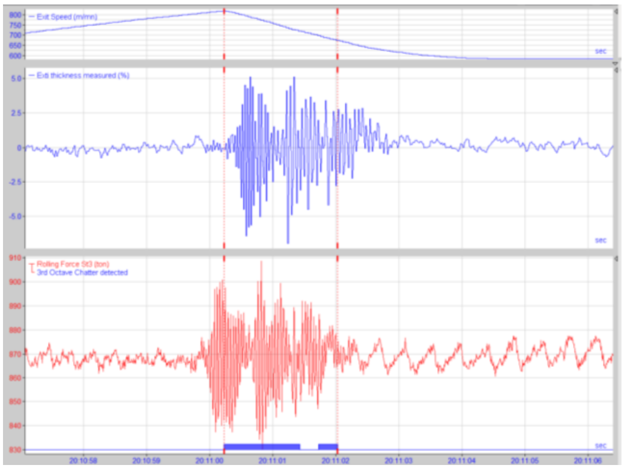

Figure 5. Rolling force variation (in red) followed by thickness disturbance (blue) in a third-octave chatter event.

Based on this detection by the pressure transducers, an algorithm was designed to automatically slowdown the cold mill when such oscillation is present in the system applying the same emergency deceleration ratio defined for the manual pushbutton.
This algorithm was a great achievement since it relied on instrumentation already available in any modern mill requiring zero investment to be implemented.
Additionally, it was observed during the test phase that this algorithm would detect the chatter event and actuate on the mill speed approximately 1.2s faster than manual intervention by mill operator, potentially preventing several strip breaks caused by third-octave mill chatter.
The downside of this approach is that it relies on rolling force oscillation, which is invariably accompanied by thickness disturbances and thus quality losses. Another limitation of this method is that fifth-octave chatter remained unmonitored and could occur again at any time. Because of this, it was clear that a different approach is required.

2.3 Accelerometer Detection

The investment analysis carried out has indicated that a complete solution, which would include chatter detection sensors, software to investigate the events, commissioning, etc., could easily reach seven digits figures and they were considerably higher than the available budget.
A significant portion of the investment would be engineering costs related to identification of the right positioning of each sensor and commissioning for frequency filtering, alarm threshold definition and so on.
On top of the high cost, another downside of off-the-shelf solution is the proprietary software offered by each of the potential suppliers. Each one provides their own solution which require additional training to engineers and technicians, equipment (servers, switches, etc.), adjustment to existing database to treat the new signals, and so on.

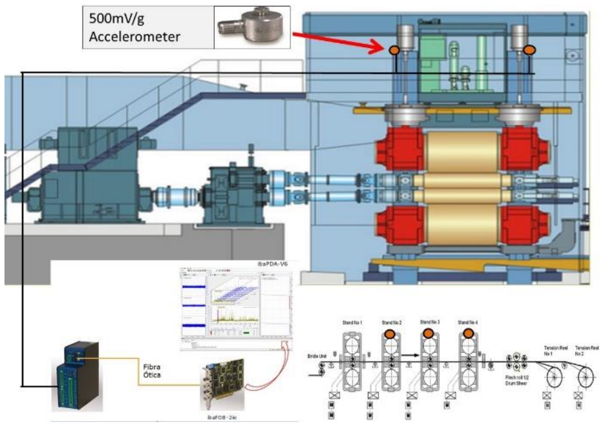

Figure 6. Schematic of accelerometers mounted on top of the mill houses.

On the other hand, the discussions with cold mill engineers inside ArcelorMittal in Canada, United States, France and Belgium have proven that with little investment and dedication of skilled

engineers a simple but efficient chatter detection system could be developed.
Because of these downsides of off-the-shelf solutions and considering the vast experience of other ArcelorMittal plants in developing their own chatter detection system, AMV decided to follow the same path and have an in-house solution.
The first step consisted in the instrument-tation of the mill with the installation of vibration sensors.
These analog sensors have been con-nected to a dedicated piece of hardware which was able to acquire their high sampling rate and send the converted digital signal to the existing data acquisition system (DAS). These digital signals would then be filtered by the DAS in order to separate the third-octave (110 to 130Hz) and fifth-octave (300 to 700Hz) chatter frequency ranges to allow further data processing.

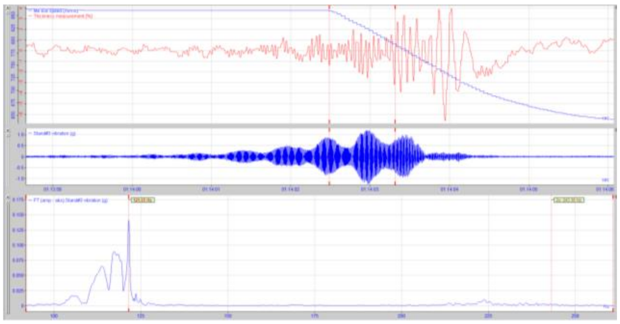

Figure 7. Vibration signal from accelerometer on top of mill housing in time and frequency domains.

An algorithm has been developed to detect chatter events within the filtered frequency ranges. According to the vibration level, the system would then send a signal to the mill controllers to automatically reduce the line speed in only 4ms. Additionally, the algorithm verifies the thickness signals for variations due to chatter and flag the coil for reprocessing at downstream lines.

3 Results and Discussions

Each of the three different actions proposed to reduce the impact of chatter occurrences have yielded good results to some extent.
The pushbutton installed in the operation control panel, for example, even though relying on operator’s ability to swiftly identify the chatter and react, have provided the tools to leave the third-octave speed range in much less time then before. It’s dependency on operator’s experience and understanding of the phenomenon, on the other hand, have reduced its efficiency.
The detection of rolling force oscillation due to stand vibration was developed to solve this issue by utilizing a well-defined and standardized algorithm to identify the chatter events at an early stage and automatically actuate on the line speed 1.2s faster than the average operator. As it relies on pressure transducers which measure the rolling forces, an instrument already available on any modern tandem cold mill, zero investment was required to implement this function in the control system.
Nonetheless, this detection is only possible when unacceptable thickness disturbances are already being generated by the vibrating stand. In addition to this limitation, the fifth-octave chatter mode could not be detected by these actions which kept the strip quality in constant risk of being jeopardized again at any moment.
The accelerometers mounted on top of the mill stand, in alliance with fast data acquisition and processing and a dedicated algorithm, on the other hand, are able to detect both third-octave and fifth-octave chatters at an early stage, preventing thickness variations, strip breaks and quality losses.

4 Conclusions

After the implementation of these actions, at least one event of fifth-octave chatter has been detected. In this occurrence, the system warned the operators about the vibration level on the fifth-octave frequency range and requested a visual inspection of the backup rolls, which revealed that there were chatter marks on it. As the event was early detected, the number of coils affected was minimal and the financial losses were very low as these coils have been downgraded before being sent to the downstream lines.

After the implementation of these actions, the number of coils downgraded due to thickness disturbances caused by third-octave chatter have been reduced by 40% as a result of the much faster actuation on the rolling speed.

These results are satisfactory considering that the implementation of these actions have been carried out with virtually zero investments.

Additionally, the information provided by the accelerometers installed on top of the mill house have provided valuable indication as to where the excitation for the chatter occurrences are coming from. This has allowed the engineers to go further into the investigation of the root causes of the vibrations and how to minimize these events. This study is ongoing and additional results are expected for the coming months.

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