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Application Note

Case study – Vibration monitoring of tandem mills at the Arcelor Mittal Tilleur cold rolling mill

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ABSTRACT

The Arcelor Tilleur cold rolling mill has a 5-stand tandem mill that is prone to 3rd order chatter and a 4-stand tandem that is subject to 5th order chatter. The COMPASS vibration monitoring system is being successfully used at the Tilleur for both machine condition monitoring and product quality control of the tandem mills.

Chatter vibration can affect both the quality and production capacity of cold rolled steel if it is not properly monitored and reduced. 3rd order octave chatter is a self-generating resonance caused by the inter-reaction of the strip and mill and can quickly reach destructive proportions if the speed is not reduced quickly enough. 5th order chatter is also a resonant condition, but it is most often excited by machine defects that can result in visual barring of the strip if the source of the excitation is not removed.

Property	4-stand Mill	5-stand Mill
Mill speed		
Entry	370 m/min	360 m/min
Exit	1187 m/min	1835 m/min
Rolling force	2200 tonnes/stand	1600 tonnes
Power		
Stand 1	5.6 MW	2.2 MW
Other stands	6.6 MW	4-10 MW
Tension		
Entry	25 tonnes	4.6 tonnes
Exit	10 tonnes	Max 10 tonnes
Roll diameter		
Working roll	535 mm	500-585 mm
Back-up roll	1422 mm	1200-1365 mm
Strip thickness		
Entry	1.60-5.00 mm	1.60-4.00 mm
Exit	0.25-3.20 mm	0.16-1.00 mm
Rolled steel type	Carbon steel	Various steels
Strip width	600-1524 mm	600-1250 mm
Coil diameter	1000-2400 mm	1000-2135 mm

Table 1. Characteristics of the two cold roll tandem mills at Tilleur.

The Tilleur cold rolling mill is one of six different plants that are all involved in cold rolling and finishing processes in the Liège area under Arcelor Mittal's flat carbon steel sector (APPW, Arcelor Produits Plats Wallonie). Tilleur has 391 employees and produces 1.87Mt of cold-rolled full-hard mild carbon steel coils each year (Figure 1).

Tilleur is supplied with hot rolled coils from steel mills in France and Luxemburg and produces cold-rolled full-hard steel coils that are exported to nearby plants for

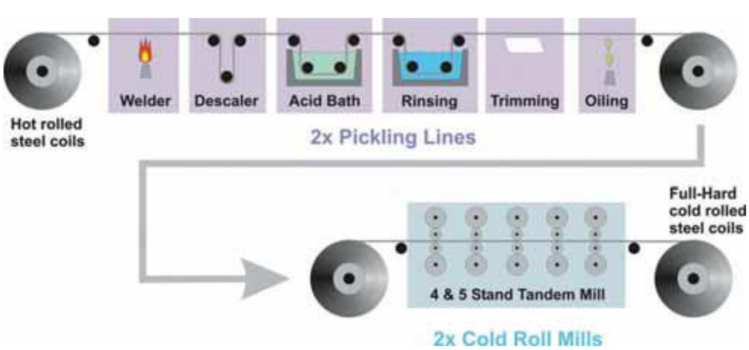

Figure 1. Tilleur has two pickling and two cold roll tandem mills.

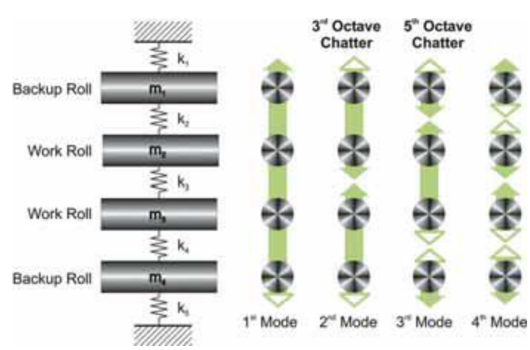

Figure 2. Vibration modes of a stand with four degrees of freedom.

further processing (e.g. galvanizing, annealing, tinplate and organic coating). The steel coils are used in the packaging, appliance and automotive industries. As Tilleur is the only cold rolling mill in the area, the other five finishing and coating companies are completely dependent on it.

The 4-stand, 4-high tandem mill is used for making a single product for the automotive industry but the 5-stand mill is used for a range of different thin-strip products for the packaging and appliance industry (mostly tinplate). The main parameters of the two mills are given in Table 1.

Cold roll product quality

Thin, cold rolled steel is a surface-critical product with little tolerance for surface defects. There are two primary sources for steel product surface defects:

- Roll surface defects
- Chatter vibration

Defects on the rolls will directly transfer to the strip. The distance of the marks will be constant, no matter what speed the strip is moving. Roll defects could be caused by a number of factors, such as grinding faults in the roll itself, or deformation caused by the hydraulic clamping system.

The steel strip surface can also be visually or physically affected by roll vibrations called chatter. These vibrations are speed related, meaning the vibration changes as the strip speed changes. Chatter vibration is the result of a back-up or work roll resonance in one or more stands of the cold roll mill, which is excited by the elastic properties of the steel product itself and/or by external forces from the machine.

There are four primary vertical vibration modes of a roll stand with four rolls, as shown in Figure 2. Only the second and third vibration modes can affect the surface quality of the steel, also known as the 3rd and 5th octave vibration modes, respectively.

3rd octave vibration chatter

Third octave chatter vibration occurs at 110-170Hz, which is the natural frequency of the back-up rolls that resonate out-ofphase. It is self-excited vibration instability condition that is created by interaction of forces between the elastic strip together with the resonant characteristics of the mill structure in the form of a positive feedback loop. It is a function of the inter-stand properties of the steel product such as the strip tension, thickness, strip speed and other factors such as the type of steel, strip width, amount of reduction, friction factor, roll force, roll bite, and lubrication.

The build-up of vibration at the natural frequency of the mill is regenerative and therefore can reach destructive proportions within less than 5 seconds. It can result in unacceptable thickness variations of the strip and even strip rupture.

The primary method of control is reducing the strip speed, but the vibration levels can also change when other process changes are made such as the roll bending forces. Reducing strip speed has a negative effect on productivity, but it saves money by reducing the number of coils that are rejected, and by reducing downtime associated with strip ruptures and damaged rolls.

5th octave vibration chatter

Fifth octave chatter vibration occurs at 550-650Hz, which is the natural frequency of the work rolls that resonate in-phase. It generally occurs in the highest speed stands. If the vibration level is not reduced, it can spread to the other stands via the strip. There are many potential causes for exciting the 5th octave vibration. Sometimes it is necessary to do modal analysis with an instrumented hammer to find the external forces that are exciting the resonance. Often, the external forces that excite the 5th octave mode resonance are related to problems with the rolls, motor, shafts, bearings and gearbox. This could be grinding the rolls with small imperfections, or faults in the roll machine itself such as spindle and liner clearances, work roll bearing defects, hydraulic pressure system on rolls, vibration from worn pinion gears, gear mesh frequencies, passage of key ways in back-up roll necks through the load zone, and unbalance.

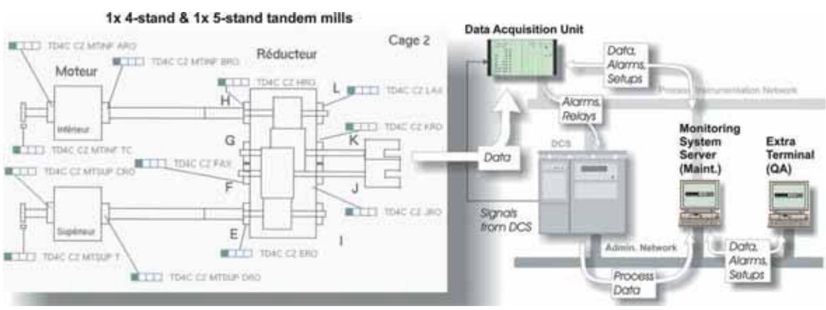

Figure 3. Condition monitoring system configuration for the 4 and 5-stand tandem mills at Tilleur.

Over time the back-up rolls become marked by chatter vibration where the continued presence of the resonant vibration slowly wears transverse marks into the roll surface. The process is exacerbated if the frequency of the forced vibration excites mill resonances in the fifth octave range. If the back-up rolls are not changed at this time, the chatter marked rolls will transfer these to the work roll and to the strip itself as transverse bands that can be seen on both sides of the strip without thickness variation (chatter frequency can be calculated by dividing the strip speed by the banding bar spacing in like units).

Controlling this chatter vibration level can be achieved superficially by changing speed or roll force, but it is more a question of identifying and then isolating or removing the external vibration source that is exciting the resonance frequency. If it is caused by a fault in the motor, gearbox, drive assembly fault, or excessive journal bearing clearance, this will have to be corrected. If the external frequency excitation is caused by work roll bearing defects, there are a couple of solutions. If the bearings are exhibiting a brinnelling type fault (many points of impacts on the race), the bearing can be put on a different stand where there is no 5th octave mode vibration until it can be replaced at a convenient time. If the fault is a spall (a single impact flaw on the race), this can be rotated out of the load zone. Of course if the back-up rolls have been subjected to high levels of vibration over a period of time and are marked, these will have to be replaced (this is sometimes carried out several times per shift). The back-up rolls could also be subjected to mechanical fatigue due to prolonged operation within its resonance frequency. To prevent this, one or both rolls can be replaced to change the mass and hence reduce or increase the natural frequency so it will no longer be excited by the external forced vibrations.

Condition & product quality monitoring

There are two technicians and a manager/diagnostic specialist in the condition-monitoring group at Tilleur. They take care of all monitoring in the plant, using both an off-line and on-line monitoring system.
The on-line monitoring system is used for the following purposes:

- Automatic condition monitoring – early detection of developing faults in motors, bearings and gearboxes of the rolling mills. This is not only for minimising machine downtime and maintenance costs, but also for minimising the source of external vibration that could excite chatter vibration, a part of the product quality monitoring function.
- Diagnosis and analysis – evaluate the nature and severity of the developing fault so maintenance can be planned ahead of time.
- Product quality monitoring – identify 1x and chatter vibration early before it can affect the strip quality, and evaluate the accumulated severity of the vibration over time to determine when the rolls should be changed.

Product quality monitoring is the primary objective for using a monitoring system on a cold rolling mill. It is important to monitor chatter vibration in order to:

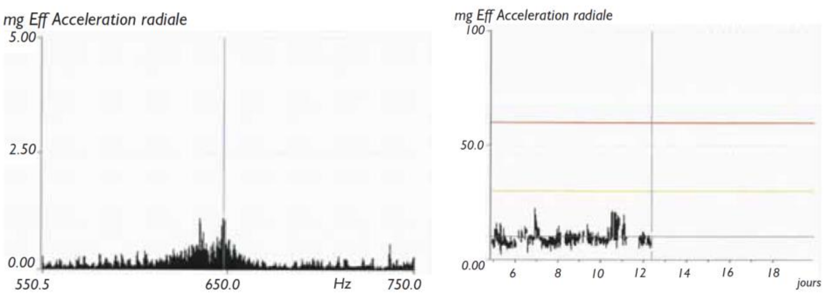

Figure 4. 5th octave chatter vibration from 4-stand mill shown in an FFT spectrum plot (left) and as a bandpass trend measurement (right).

- Optimise steel production speed
- Reduce strip thickness variations and visual marks
- Reduce strip breakage and strip waste.

Monitoring configuration

40 transducers were installed on the 5-stand mill in 2000, and 80 sensors on the 4-stand mill in 2001 for detecting and diagnosing developing faults, as shown in Figure 3. Most of these are used for both
monitoring the condition of the motors, bearings, shaft, gearboxes and rolls and also for identifying component fault frequencies that could excite 5th octave chatter vibration.

For detecting chatter vibration frequencies, a single accelerometer is mounted on top of the back-up roll pressure cylinder for those stands where there is a potential problem. Ideally the sensor would be installed directly on the bearing chocks but there is a risk that the sensors are damaged when the rolls are changed. In any case the sensor mounted on top of the stand has demonstrated that there is sufficient sensitivity to detect the relevant signals.

Fault detection, diagnosis & control

The 4-stand mill is running the same product at a constant speed and constant process conditions, and the strip thickness is greater than the products rolled on the 5-stand mill. There is little risk for 3rd octave mode chatter vibration to occur on this mill, but it is prone to 5th mode octave vibration chatter. The frequency of interest is around 650Hz. The main problem for analysis is understanding the mode of vibration conditions that leads to the problem. Modal analysis has been performed to identify the roll resonance frequency and any external vibration frequencies that can excite the resonance frequency.

A 0.5-1000Hz FFT (Fast Fourier Transform) spectrum and various FFT zoom spectra are used for diagnosis, determining the severity of chatter vibration and for identifying the new resonant frequency after a roll change. It can also be used for identifying component fault frequencies that could excite the chatter vibration. FFTs with other frequency ranges are used for diagnosing faults of other machine components.

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