Vibration diagnostics in rolling mills

A multitude of vibrations occurs in rolling mills that influence the durability and operating condition of the plant and the product quality. Vibrations can lead to component failures, speed variations, surface defects and strip thickness undulations, and many are inter-linked through cause and effect. An overview of rolling mill vibrations, the procedure of vibration diagnosis for the analysis of causes and effects leads into possible measures for reduction of vibrations.

Rolled products are subjected to a variety of quality requirements – some of the highest being for strip for the car industry, although the demands for ‘faultless’ strip continue to rise for all products especially for thickness, flatness and surface variations. These growing requirements run in tandem with the need for better plant productivity, achieved via rolling wider strip, using higher roll forces and drive torque, and higher production speed. These demands can be negated by mill vibration effects unless they are properly understood and controlled. Figure 1 shows a typical modern 6-high strip rolling stand.

VIBRATION OF ROLLING MILLS
Rolling mills have a complex dynamic behaviour, being non-linear, time-variant systems with high modal density. The vibrations and their causes may subdivide into the following categories:

- Excitation proportional to the speed of rolls, reels and coilers by unbalance or eccentricities, as well as in consequence of roll ripples
- Determinate excitation based on roller bearings or floating bearings
- Speed proportional excitation out of the drive system by misalignment, tooth engagement and gear defects
- Periodic excitation by defects from upstream processes (eg, transverse waves of the incoming strip) or out of ancillary equipment (eg, periodic grinding faults on the rolls), as well as of the process control
- Step- or impact-excitation, eg, as a result of slackness, process interruption and control discontinuities
- Stochastic excitation by friction in bearings and gearings, rolls and the forming process
- Self-vibration of the drive system, especially in the first torsion mode, by speed proportional forced-excitation as well as self-excitation (torque chatter)
- Self-vibration and movement of the roll chocks, especially by self-excitation (chock chatter)
- Self-vibration of the roll stand as vertical vibrations of the upper against the lower roll set, eg, by self-excitation (gauge chatter)
- Self-vibration of the roll stand in higher rigid body modes and bending modes of the rolls by forced and self-excitation (roll chatter)
- Self-vibration of the strip, dependent on the strip tension, strip width, unsupported strip length and vibration mode, and also by self-excitation (strip chatter)

During rolling different excitations can interfere in a wide frequency range. Self-excitations are especially critical because the vibration system takes energy from within the...
critical feedback of cause and effect, but also to devices in different processes, eg:

- backup roll ⇔ work roll ⇔ strip
- roll set A ⇒ bearing ⇒ roll set B
- \( \ldots \) ⇒ stand X ⇒ strip ⇒ stand Y ⇒ \( \ldots \)
- \( \ldots \) ⇒ hot mill ⇒ strip ⇒ cold mill ⇒ strip ⇒ temper mill ⇒ \( \ldots \)
- grinder ⇒ roll ⇒ mill stand ⇒ strip ⇒ \( \ldots \)

An important vibration-induced fault class in rolled strip are periodic product defects transverse to the rolling direction, so-called 'chatter marks' or 'waves', 'ripples', 'stripes', 'shades' or 'corrugations' (see Figure 2). Normally hybrids of thickness, shape and roughness variation and periodic impacts occur with varying wavelength and amplitude which, within certain limits, are not visible or not objectionable. The dominance of one fault may become problematic when the amplitudes increase, resulting in lower grade product or the process being interrupted.

The wavelength depends on the rolling speed and the vibration frequency (eg, 10Hz for drive vibrations, and up to 2,000Hz for roll vibrations), and may reach several millimetres, or even several metres. The fault amplitudes are in the range of 'invisible' up to approximately 20µm for shape waves, but to 200µm for thickness waves.

The reasons for periodic strip faults are mostly a superposition of different direct and indirect factors but, in principle, they can be of two types: eigen-dynamic of the plant or periodic changes in the production system (see Figure 3).

**REDUCTION OF VIBRATIONS**

Plant- and process-caused vibrations during rolling cannot, in general, be avoided, however, some influence is possible by the following measures:

**Avoidance of causes** The most effective method for vibration reduction is to avoid or minimise the causes. Defects in bearings, gear wheels or rolls may be eliminated by failure analysis and machine maintenance. Because of the complexity of rolling mills, such troubleshooting is often only possible by use of vibration diagnostics.

**Damping, detuning, absorption** Based on structure analysis, classic techniques of vibration damping, detuning by system modifications, as well as absorption of a dominant vibration, may be taken into account. In some cases, an improvement can be achieved by structure optimisation. The application of a passive damper or absorber is unlikely however. Use of adaptive damping systems may be successful for drive train vibrations and reduce roll-set vibrations.

**Decrease of self-excitation** The prevention of self-excited vibrations is an essential objective because of the extreme consequences. The energy flow into the vibration system, which may lead to very high and rapidly increasing amplitudes. Excitation as well as vibration behaviour are constantly changing as a result of variations of the product (dimension, material), of the process (speed, forces), and of the plant (rolls, bearings), overlaid with rather slow changes caused by general wear of the equipment.

**EFFECTS OF VIBRATIONS**

Substantial vibrations can have negative influences on productivity:

- On the product (lower quality or rejects)
- On the plant (increasing wear and defects)
- On the process (speed reduction and idle time)

Torsional vibrations of the drive system may lead to damage of the equipment (gearing defects, enhanced slackness, shaft fracture), and to periodic variations of the process. These variations in equipment can then lead to increasing vibration excitation.

Rolls with surface defects may reduce product quality by direct fault transfer and may excite vibrations of the whole roll stand. Thus, strip faults would be intensified, devices of the stand and the drive damaged, and roll defects further increased. Thus faults can spread in the mill stand by this
system cannot be interrupted so the feedback and the switch mechanisms have to be suspended. Because of the sporadic appearance as well as the varying nature of the influencing factors, preventive measures have not yet been successful, although theoretical models have been developed and stability investigations performed. Process parameters with a lower tendency to self-excitation are mostly the result of operator experiences and of experimental system analysis.

**Monitoring with intervention** The last possibility for vibration reduction during rolling is data based, model supported and condition-related monitoring, and the use of the derived diagnosis, prognosis and intervention for online changes of process and/or plant (see Figure 4). Vibration-relevant process parameters for online variation for cold rolling mills are, for example, the rolling speed, strip tension, rolling force and friction.

The application of a vibration monitoring system is, however, not only useful for an online intervention. The collected data can also be useful for troubleshooting and trend analysis, to determine a guideline for maintenance and even for a general optimisation of plant and process (see Figure 5).

**VIBRATION DIAGNOSTICS**

The procedure for vibration diagnostics is shown in Figure 6. At first all possible vibration causes were collected for the special rolling mill, including analysis of detail drawings and specifications from the manufacturer and of the operating company. This information is the basis for measurement planning, ie, of measuring points, test time, measured variables, measuring system and so on. Due to the different manner of driving during measurement and to the special data analysis in time- and frequency-domain, the components of speed proportional vibration, eigen-vibration and disturbing signal were separated.

On the theoretical side, the defect frequencies of each component were calculated based on the actual values of the plant (eg, roll diameter) and of the process (eg, lead and slip). The fault correlation between theoretical defect frequency and measured vibration frequency results from the speed of the corresponding component. After cause estimation, possible methods for elimination or reduction are worked out.

Because of the multitude of fault possibilities (eg, some hundreds of excitations by defect frequencies and their harmonics exist in a 6-high stand), more detailed analysis is often necessary. A precondition for a successful correlation is detailed knowledge of the respective component speed. Thus the first procedure at failure troubleshooting is the higher accuracy estimation of the speed, eg, by special measuring methods or by calibration with the vibration frequencies. The next steps are the checkups of the theoretical and actual values, the enhancement of the possible origin to secondary or upstream plants, as well as advanced measurements within...
Gauge chatter and strip break in a tandem mill

Vibrations of about 125Hz – so-called gauge chatter – occurred frequently in a tandem mill. The effects of these vibrations were distinct thickness variations with a wavelength of about 70mm and amplitudes up to 100µm. The only possibility for vibration reduction was a rapid slow-down of the rolling speed. However, often the gauge chatter could not be recognised at an early stage by the operator, resulting in strip breaks with extensive damage and idle time (see Figure 8).

To investigate the vibrations, comprehensive measurements were made, and strip probes were gauged for failure correlation. An unstable self-excitation was analysed, where the upper against the lower roll set vibrates nearly in a rigid body eigen-mode.

By installation of a monitoring system, with frequency-selected evaluation of the fault vibrations and automatic adaptation of the rolling speed, the vibration induced strip breaks were completely avoided.

EXAMPLES

Backup roll ripples in a 4-high temper mill

Two dominant failures on the backup rolls were the motivation for the investigation at a tandem temper mill: chatter marks with a distance of about 18mm and 55mm that occur separately or even superposed with different values. For the analysis vibration measurements were done and recorded by a monitoring system. Based on the signal display in time- and frequency-domain the 18mm defect could be identified as the result of eigen-vibrations in the range of about 1,270Hz (see Figure 7). In contrast the 55mm defect was generated by a speed proportional failure of 77 times the backup roll speed. Even though both faults had an analogue appearance and occurred at the same time, the origination mechanisms were basically different.

Strip thickness variations in a reversing stand

Significant thickness variations in special product qualities were the reason for analysis of the thickness signals of a 4-high reversing stand. The comparison of the measured strip undulations was carried out by means of spectrograms in relation to the mill speed. Signals of strip thickness variations and their spectrograms with reference to the rolling speed, are shown in Figure 9.
The incoming strip contained periodic thickness variations of light amplitude (several horizontal lines in the region of constant speed at 2Hz up to 6Hz) from upstream processes. The critical thickness variations were proportional to the speed of the up-coiler (dying out line in the phase of constant speed from about 2Hz basic frequency at the pass beginning down to 1Hz at the end), and a result from vibrations of the system up-coiler, strip, mill stand, roll gap setting and rolling force.

**Analysis of a backup roll grinding machine** The vibration behaviour of a backup roll grinding machine was recorded and analysed for ripple formation. The measurement was obtained by use of acceleration sensors in three directions at the gearing housing, the roll bearing and the grinding headstock. Related signals were the speed and current of the roll motors, the grinding wheel and the slide feed motion.

To avoid self-excited vibrations the roll drive and the wheel drive could vary with a frequency of about 40mHz. As speed proportional excitations were not yet influenced, forced excitations by the chain drive with 192 teeth and excitations proportional to the grinding wheel speed and its harmonics were detected clearly (see Figure 10). Eigen-vibrations with low amplitude were measured in the frequency range of 20-400Hz, but without signs of self- or parameter-excitation. Increased amplitudes, which could be relevant for roll ripples, occurred by a combination of the eigen-frequency at about 270Hz and excitation from the chain wheel within the twofold number of teeth.

**CONCLUSIONS**

Vibrations in iron and steel plants are becoming an increasing problem because of the rise in quality standards, soaring cost pressure, and the demands for faster and bigger plants that are reliable in operation and process. Vibration diagnostics is a suitable measure to identify fault vibrations in rolling mills, levellers, strip processing lines, etc., and to locate their causes. On that basis it is possible to develop techniques to avoid or to reduce the trouble and finally to attend its realisation.

Only by a combination of different measures, will it be possible to come closer to ‘faultless’ production. The subjects of current research are, therefore, total process monitoring systems, their integration into the production system and the inclusion of adaptive techniques for vibration reduction into the total optimisation concept.

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