Maintenance and quality related condition monitoring in rolling mills

Dr.-Ing. J. Mackel
ACIDA-TorqControl GmbH, Managing Director
Kaiserstraße 100, D-52134 Herzogenrath, Germany
eMail: jmackel@acida-torqcontrol.de - Tel: +49 172 2576967

1 Introduction

Companies in industrialised western nations generally increase their productivity by raising the energy input into their production plants. Primary industries, e.g. the mining and metallurgical industry, are particularly affected since developing countries, or those on the threshold of becoming an industrialised nation, have an advantage through their potential of human and raw material resources. The extension of the power density introduced into a process generally requires higher maintenance and quality control standards. This entails extensive data acquisition and machine monitoring tools. Compared to standard monitoring systems, primary industries frequently have higher demands in terms of the robustness and effective measuring range of data acquisition and monitoring systems.

This paper presents monitoring and diagnosis tools designed for the requirements of modern rolling mills. The aims of extended condition monitoring and process control are to reduce maintenance costs, increase productivity and improve product quality. The paper will outline an analysis of the practical use and return-on-investment of these or similar monitoring systems. These systems are used in both the steel and aluminium industries.

A vibration monitoring system for high-speed rolling mills will initially be described. Cold rolling mills tend to vibrate at high rolling speeds under certain conditions. This phenomena is generally referred to as mill or gage chatter and causes severe damage in terms of strip quality. The vibration monitoring system presented here continuously analyses the vibrations measured on the work roll chocks. The diagnosis of the vibration signals is carried out in the time and frequency range. The signals contain a lot of structure-borne sound which does not affect the quality of the strip. This noise has to be eliminated to obtain reliable strip quality predictions. The operator is warned of critical vibrations. In addition, characteristic values and fingerprints of the vibrations are stored in a long term database to archive a quality standard for each strip.

Secondly, a torque measuring and monitoring system will be presented which was developed for permanent and continuous operation on heavy drive trains under rough ambient conditions. The monitoring system focuses on a residual lifetime prediction for main drives and on the optimisation of the rolling process. The aim is to diagnose the state of the rolling mills, thus supporting predictive maintenance strategies and quality control.

Some practical examples of the monitoring systems in rolling mills demonstrate the efficiency of the systems and of modern diagnostic tools in general.

2 Vibration monitoring system for quality control

2.1 Roll stand vibrations and their effect on the strip quality

Rolling is the most important processing method for metal produced metallurgically by melting. Flat rolling plays an important role here. A broad range of plates, strips, sheets and foils are produced in hot and cold-rolling mills. The demands made on quality assurance differ depending on the end product. The accuracy of the thickness of sheets manufactured for the car industry or for lithographic purposes has to be within the range of μm; even the slightest irregularity of texture or surface roughness is prone to render entire strips useless. What forms a challenging task in this context is the process tolerance and quality standard required of rolling plants, which usually operate with several megawatt of power, rotating roll masses between 20 and 100 tons and rolling speeds of up to 2000 m/min.

The response of rolling mill companies to international competition and global pressure for an increase in productivity is above all an increase of the rolling speed. This is particularly true for cold-rolling mills in which steel and aluminium strips are manufactured. However, higher speeds increase the power density in the process as well as the plant's potential to react with vibrations. Under certain operating conditions, vibrations or spurious oscillations may occur, which again cause gauge chatter or chattermarks on the rolling stock. Gauge chatter are periodical faults in thickness or shape of the strip or regular shades on the surface of the strip transverse to the rolling direction. Heavy vibrations of the roll stand may even cause ruptures of the strip (cf.
Figure 1) /HAN91/. Similar problems have been reported from paper mills and photographic film manufacturing.

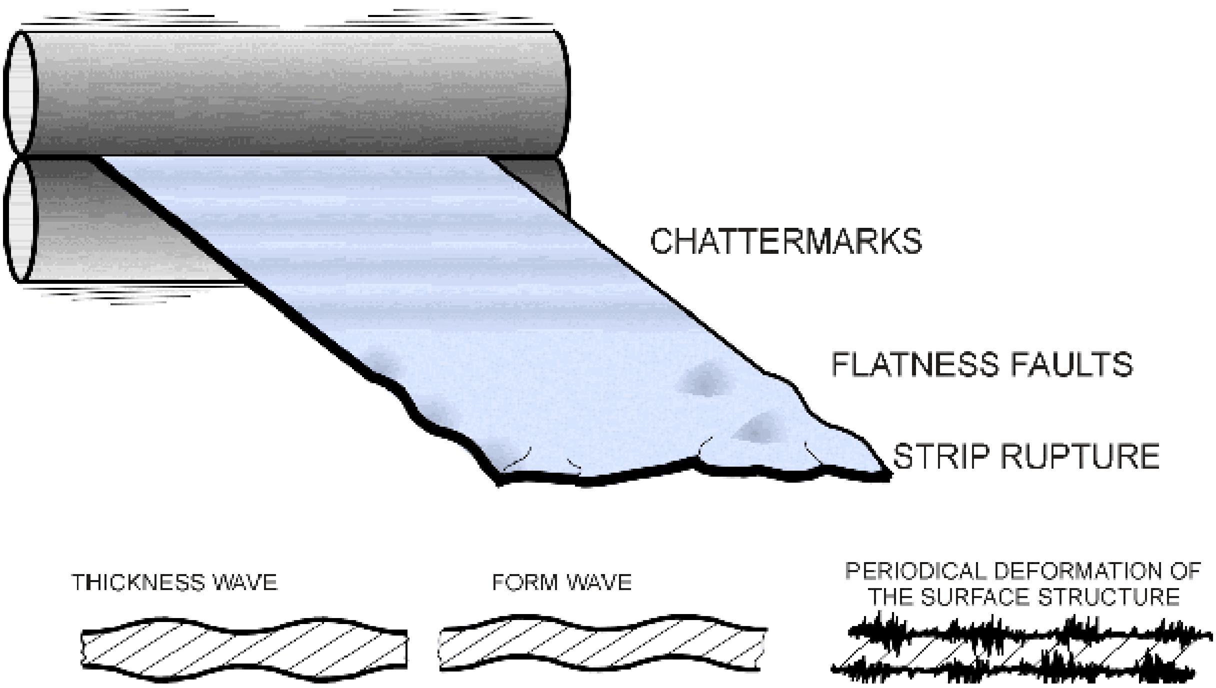

Figure 1: Possible strip faults due to rolling mill vibration

The amplitude and wave length of periodical strip faults depends on the vibration system and the vibration frequency. Two ranges of frequencies are differentiated in roll stands /MACxx/, /MAR94/, /NES93/, /ROB78/, /SEE95/, /LOU99/:

Types of rolling mill vibrations classified according to frequency:

- vibrations vertical to the roll stand, roll stand-vibrations:	1 Hz to 15 Hz
- torsional chatter, torsional vibration of the main drive:	5 Hz to 20 Hz
- gage chatter or third-octave chatter:	100 Hz to 300 Hz
- roll chatter or fifth-octave chatter:	500 Hz or higher

In addition, a differentiation of interfering frequencies into those which are proportional to the speed and those which are not may help to describe the phenomenon of vibration and its manifestations.

Causes of speed-proportional incitations:
- material damaged by gage chatter
- polygonal roll shape (rotundity error) due to vibration of the roll grinding machine
- balance error and eccentricity of the rolls
- roll bearing and tooth error
- drive irregularities, e. g. due to displacement of shaft

Causes of speed-independent incitations:
- natural vibration of the roll stand
- fluctuation of front tension
- non-homogeneity of material
- slip effects (stick-slip)
- drive vibration (e. g. drive regulation)
- chatter marks due to excessive free motion (e. g. locking or hit)
- The vibrations observed in rolling stands can also be classified in accordance with the different vibrational types known in physics:

Vibrations classified according to the vibration incitation mechanism:

Free vibrations occur when a single trigger pulse affects oscillatory systems. As soon as the pulse has been triggered, the rolling stand or parts of it oscillate with their own natural frequency.

Separately and parametrically excited vibrations in rolling stands are in general the direct effect of deficient plant or process conditions or alternatively of plant damages, such as for instance when the roller lock, the roll bearings or the drive train have too much play. Another cause are periodically changing system parameters (e. g. variation of controlled quantities).

Self-starting oscillations result from the interaction of various process parameters in connexion with the simultaneous supply of power to maintain the vibration process. What is known as the third-octave chatter of rolling stands, can be put down to self-excitation.

2.2 <u>Vibration monitoring in rolling mills</u>

No direct measures can be taken against the oscillation of roll stands since the installation of vibration dampers is usually impossible for reasons of construction. Moreover, process parameters which have an influence on the vibrations, such as lubrication, front tension or rolling force cannot be altered to a sufficient degree in most cases. The rolling speed is e.g. the only alterable control variable. Therefore, it must be guaranteed that plants are operated with roll speeds at which the oscillation level will not adversely affect the product quality. This can be achieved by online vibration monitoring systems. The aims of online vibration monitoring systems in rolling mills are quality control and supporting predictive maintenance strategies.

Piezo-electric acceleration sensors are a suitable way to measure the vibration of the roll stand. The sensors are mounted on the chocks of the work rolls. The correct installation of the sensors is of crucial importance. The harsh environment and the need to install the sensor on the chocks requires a very robust but still handy format sensor housing. Experience led to the sensor construction shown in Figure 2 which is based on a steel housing with a bayonet fixing and a protecting tube for the cabling.

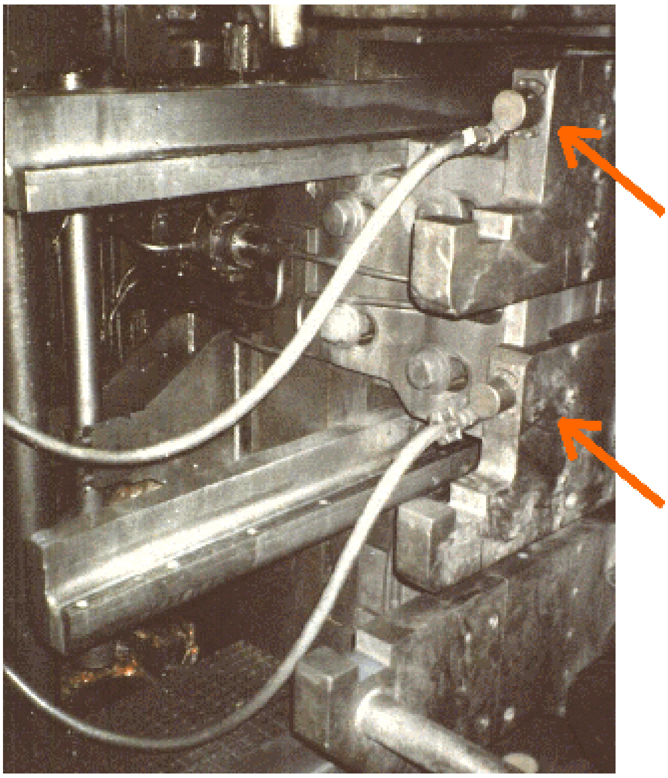

Figure 2: ***Two triaxial sensors in bayonet housings mounted on the chocks of a 6-high cold rolling mill.***

The signals of the acceleration sensors are amplified, low-pass filtered, digitised and transmitted to a computer (industrial standard PC). The result of the quality diagnosis is displayed online in the control unit. Figure 3 shows schematically the construction of the vibration measuring system /MAC98/.

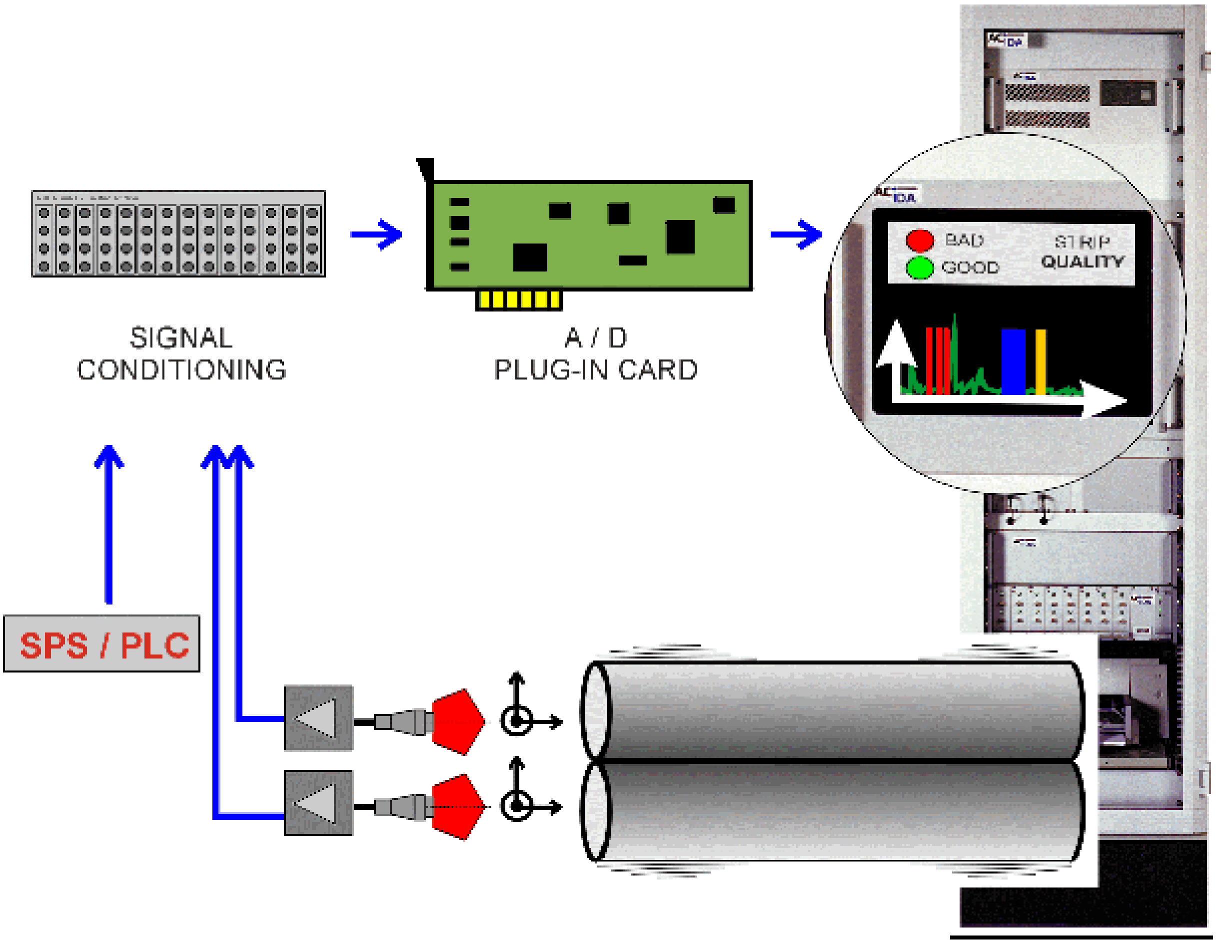

Figure 3 : Design of the online vibration monitoring system.

The visualisation of the vibrations and the diagnosis results is important for the acceptance and success of vibration monitoring systems. A threefold visualisation strategy shows the best results /MAC98/:

- The status of the product quality and of the machine is displayed in the simplest possible way, e.g. a green/red light (overall status is good/bad) and short messages in case of a bad process or machine situation. This requires fully automatic diagnostic algorithms.
- Regular printouts of a journal provide a summary of perturbations and special events. Journals also require fully automatic diagnostic algorithms and also a database to store the records and perform a statistical long-term analysis.
- The on- and offline-display of all the recorded data in different display modes, e.g. time signal, FFT-spectra, cumulative FFT-spectra, etc. allows the performance of standard signal processing and analysing operations.

2.3 Results of vibration monitoring of rolling mills

Figure 4 presents the results of gage chatter on a 5-stand cold rolling mill in terms of roll stand vibrations. During a temporary measurement the vibration initiating roll stand had to be identified. Such intensive gage chatter as shown in Figure 4 often leads to strip rupture. The results of the analysis showed that stand number five initially causing the gage chatter. The vibrations propagate via the strip to stand four and from there to stand three (identical constructions). The vibration showed a frequency of roughly 125 Hz. The modification of the upper screw down resulted in a noticeable reduction of the vibrations. Due to the success of the temporary measuring campaign, a permanent vibration monitoring system was installed at the rolling mill /MAC95/.

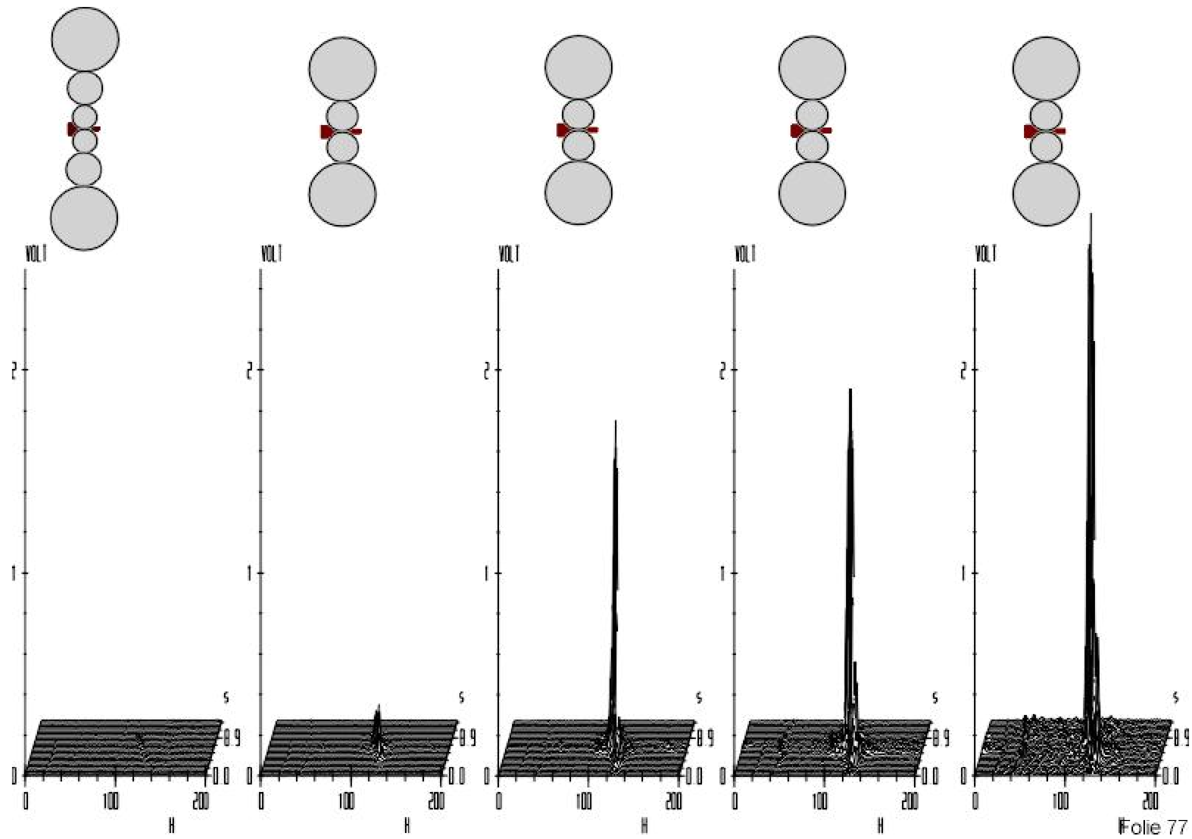

Figure 4: Gage chatter at a 5-stand cold rolling mill. The cumulative FFT-spectra of the measured vibrations are shown for all 5 roll stands.

Another example shows how mill stand resonance is exited by speed-proportional incitations (cf. Figure 5). Speed-proportional incitations are generally due to mechanical defects within the rolling mill, e.g. bearing and gear box defect or polygonal roll shape. Finding the speed-proportional incitations is of crucial importance, as they allow the detection of the original, mechanical causes of the incitations. However the analysis of cumulative FFT-spectra is often time consuming as the incitational effects depend on many strip parameters (material, width, thickness etc.), and thus do not appear during each pass.
The so called frequency-speed-collective has been developed to simplify the evaluation of the FFT-spectra (Figure 6) /FAR99/. Compared to the cumulative spectra, the benefits of the frequency-speed-collective are the greater time basis and the direct read out of the cinematic factor of speed-proportional frequencies. This is the prerequisite for automatic online diagnosis of the vibration status of rolling mills.

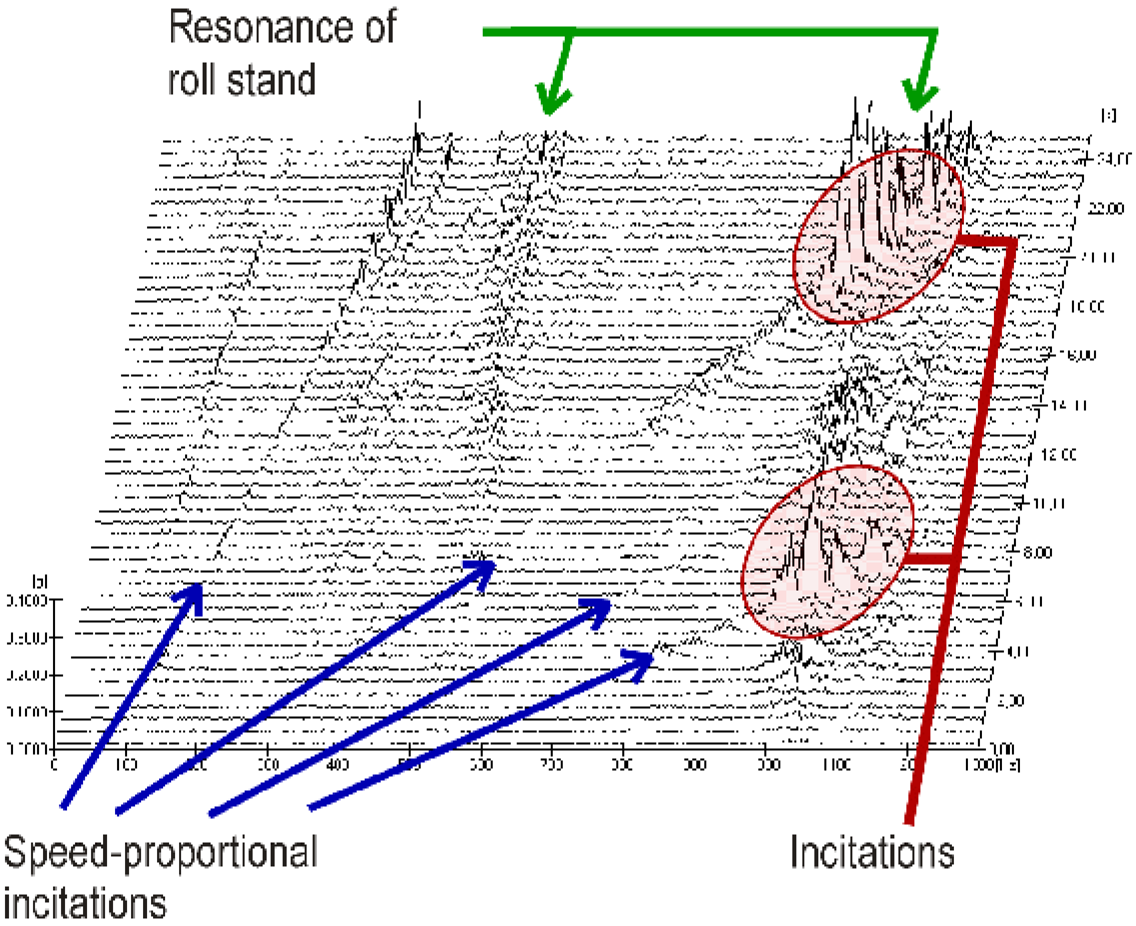

Figure 5: ***Roll stand resonances as a result of speed-proportional incitations during the speedup of the rolling mill. Duration of the cumulative spectra: 25 sec.***

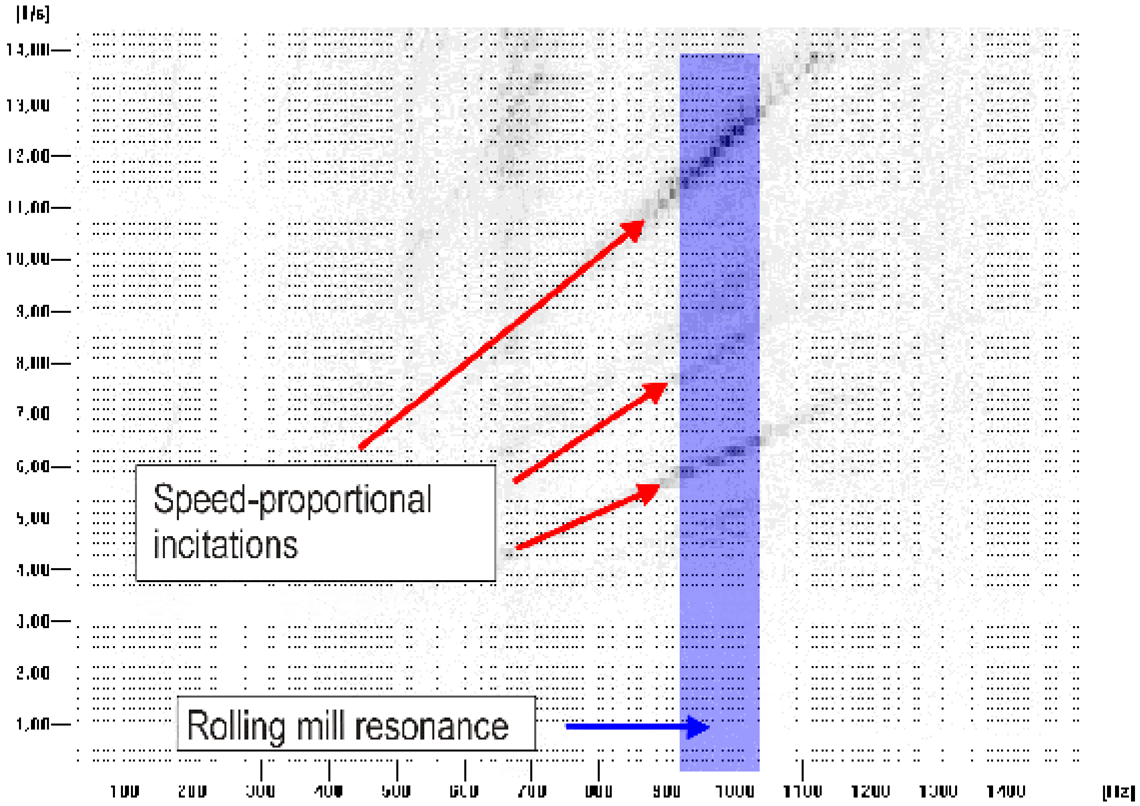

Figure 6: ***Frequency-speed-collective of the vibrations measured at the last rolling stand of a 5-stand cold rolling mill (shown here as fsc-sonogramm). Compared to the snapshot of one single speedup of the rolling mill, this frequency-speed-collective is based on the vibrations measured during the rolling of 5 coils (~ 800 sec).***

3 Torque monitoring system

The aims of torque monitoring systems for rolling mills are to support predictive maintenance strategies and to document and optimise the rolling process. A torque monitoring system consists of the torque sensor mounted on the shafts of the main drive of the rolling mill and the computer based monitoring system. To achieve the aforementioned goals, the software should have the following features /ASC98/:

- Recording, display and storage of torque and plant signals
- Classification algorithms (e.g. level-cross-counting or rainflow algorithm)
- Residual lifetime estimation based on fatigue analysis /HAI89/
- Online and offline display of time signal, frequency spectra, cumulative frequency spectra, load collective
- Monitoring of limit curves in time and frequency range
- Transient triggering (alarms)
- FIFO-like data storage in SQL database for long-term monitoring
- Intelligent report generator for email reporting
- Tele-service enhanced

The torque sensors used in rolling mills must be very robust due to the rough ambient conditions. Figure 7 schematically shows a strain gauge and telemetry-based torque measuring system. A sophisticated sealing system protects the strain gauge and the electronics on the shaft against water, oil or mechanical damage. Figure 8 shows torque sensors during operation in heavy water spray installed on an hot strip mill. Experience has shown that the reliability of torque sensors in rolling mills can only be guaranteed if the sensor operates fully contact-free, i.e. telemetric signal transmission and inductive power supply.

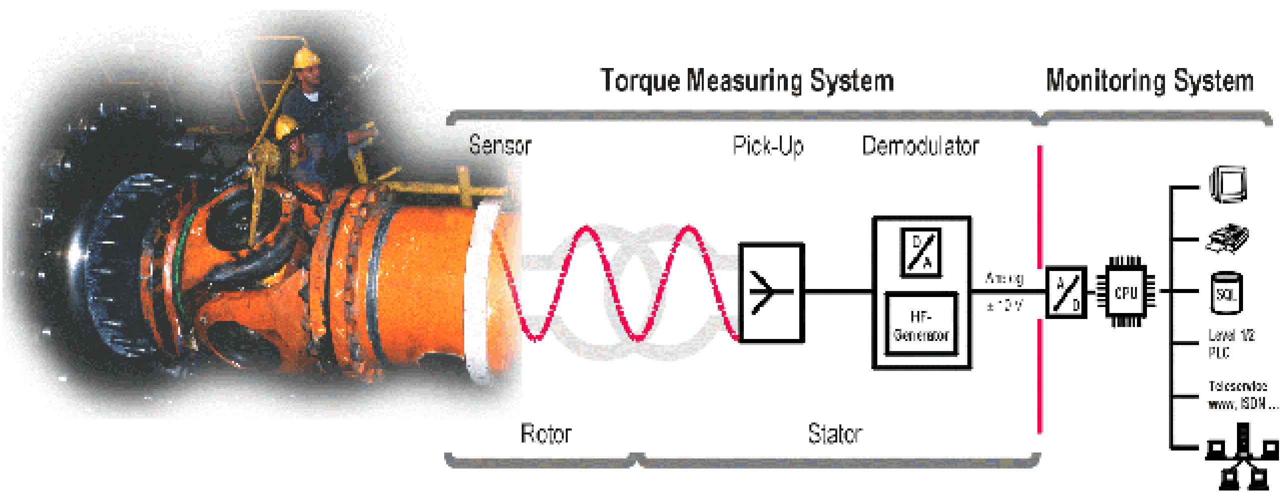

Figure 7:Strain gauge and telemetry-based torque measuring system, designed to withstand the rough ambient in rolling mills.

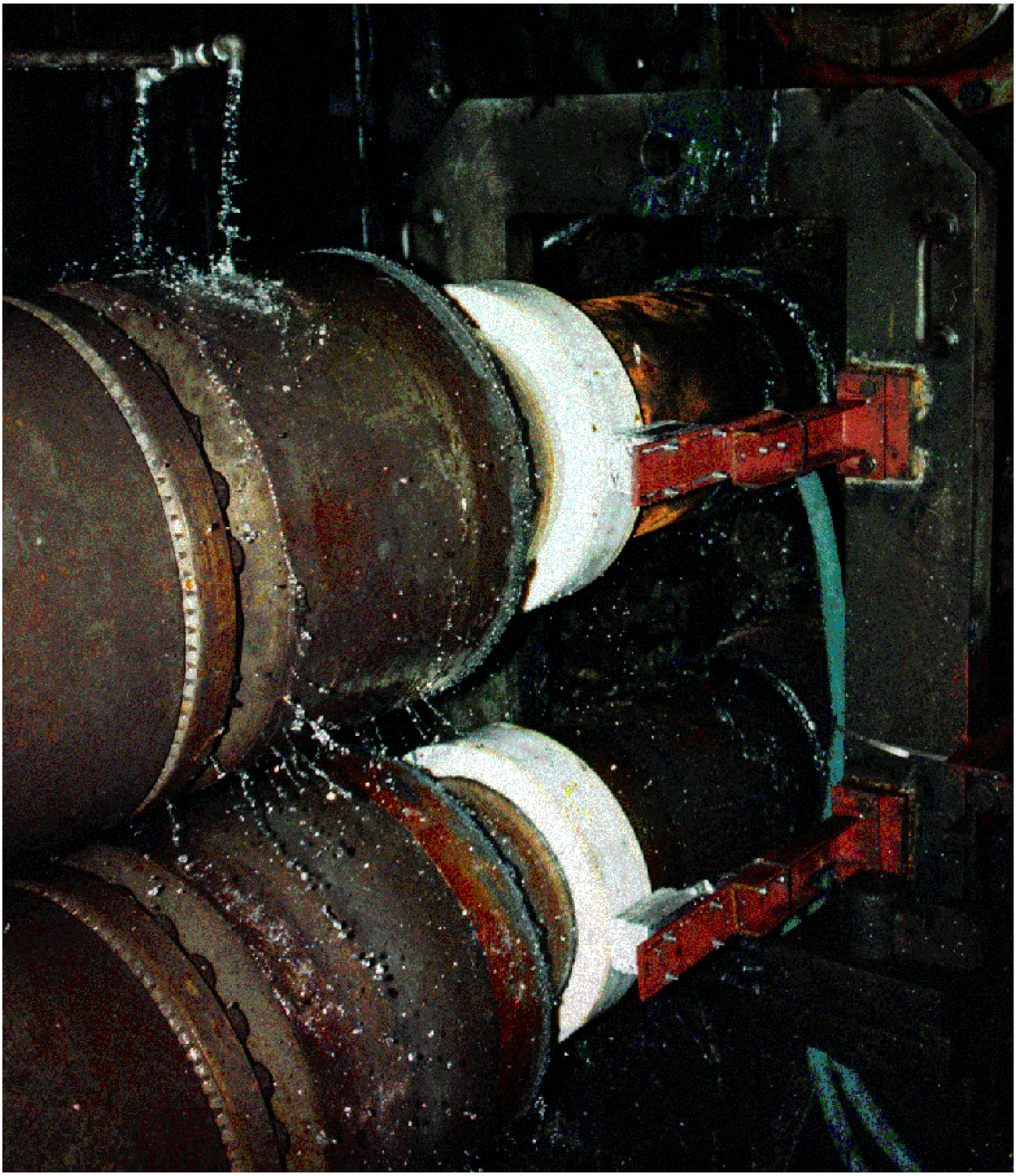

Figure 8: Torque sensors installed on the two main drives of a hot strip rolling mill.

The results of some examinations on different types of rolling mills illustrate the benefits of monitoring systems in rolling mills. The first example shows a machine-related pass schedule optimisation. This leads to longer lifetime expectations for the high loaded components of the main drive. In the example shown in Figure 9 (reversing roughing mill for aluminium) the original pass schedule foresees 23 passes for a certain material. Although this material represents only a small percentage of the yearly overall production at this mill stand, the arising torque load damages components of the universal joint at a roughly ten times higher percentage in terms of residual lifetime. The optimised pass schedule takes 27 passes and a more even distribution of the torque load. The loss of production time is insignificant, but the lifetime expectation of the spindles increases dramatically. The return-on-investment for the installed torque monitoring system was reached after only a few months.

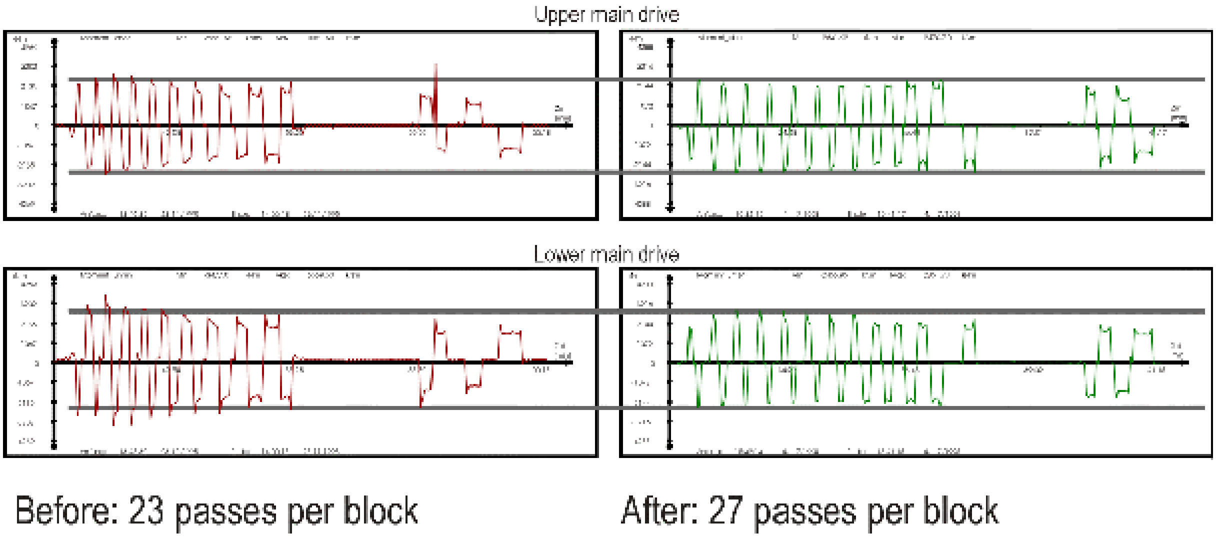

Figure 9: ***Machine-related pass schedule optimisation leads to lower torque loads.***

The detection of so-called special events during rolling can lead to a better process control. This means a constantly high level of product quality and a reduction of maintenance costs. Such a special event is shown in Figure 10. The heavy torsional chatter which occurs in the middle of the pass marks the surface of the block and causes severe damage to the drive. A process optimisation may be carried out if such events are recorded and analysed. In this case, the lubrication system was improved.

Another record of a special event is shown in Figure 11. The block was not heated homogeneously - the head of the block is too cold. During the first pass the entering torque impact is very high. During the reversing pass a similar, but inverted characteristic was observed.

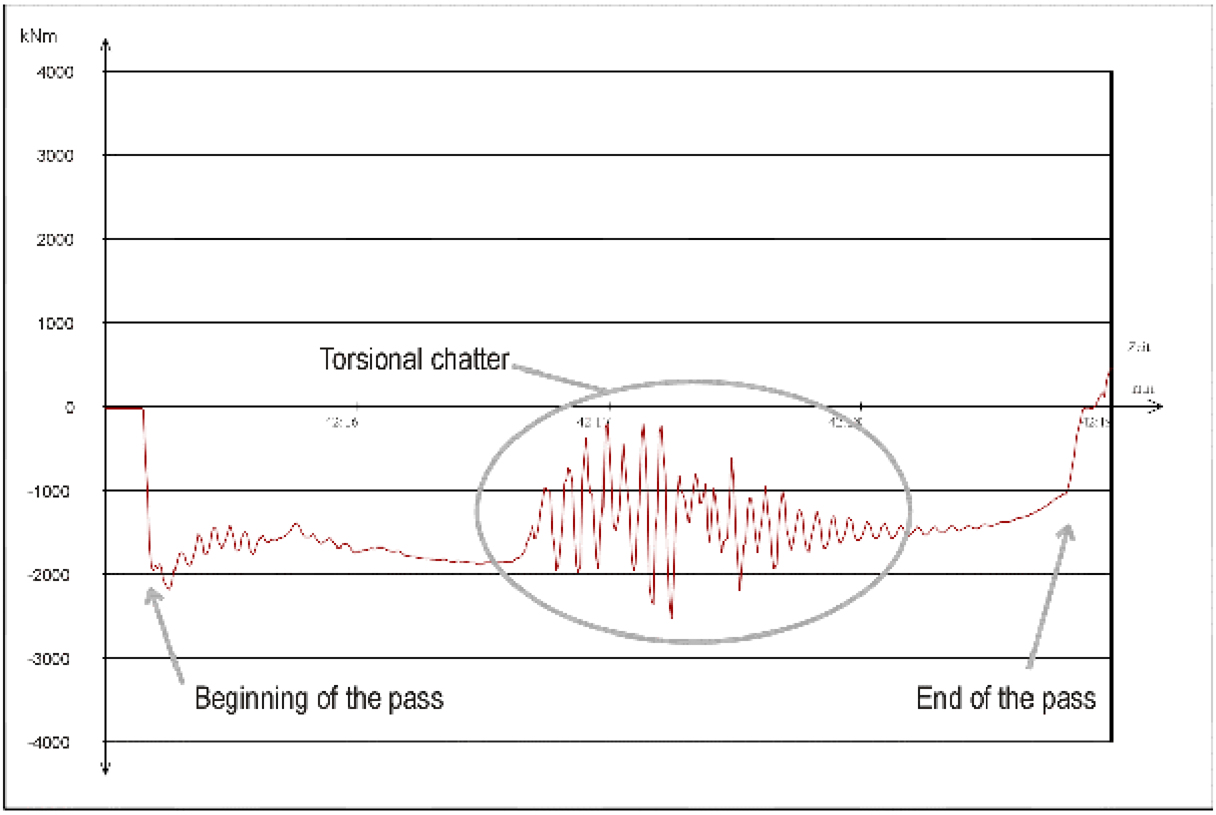

Figure 10: Heavy torsional chatter in the main drive of a roughing stand (steel)

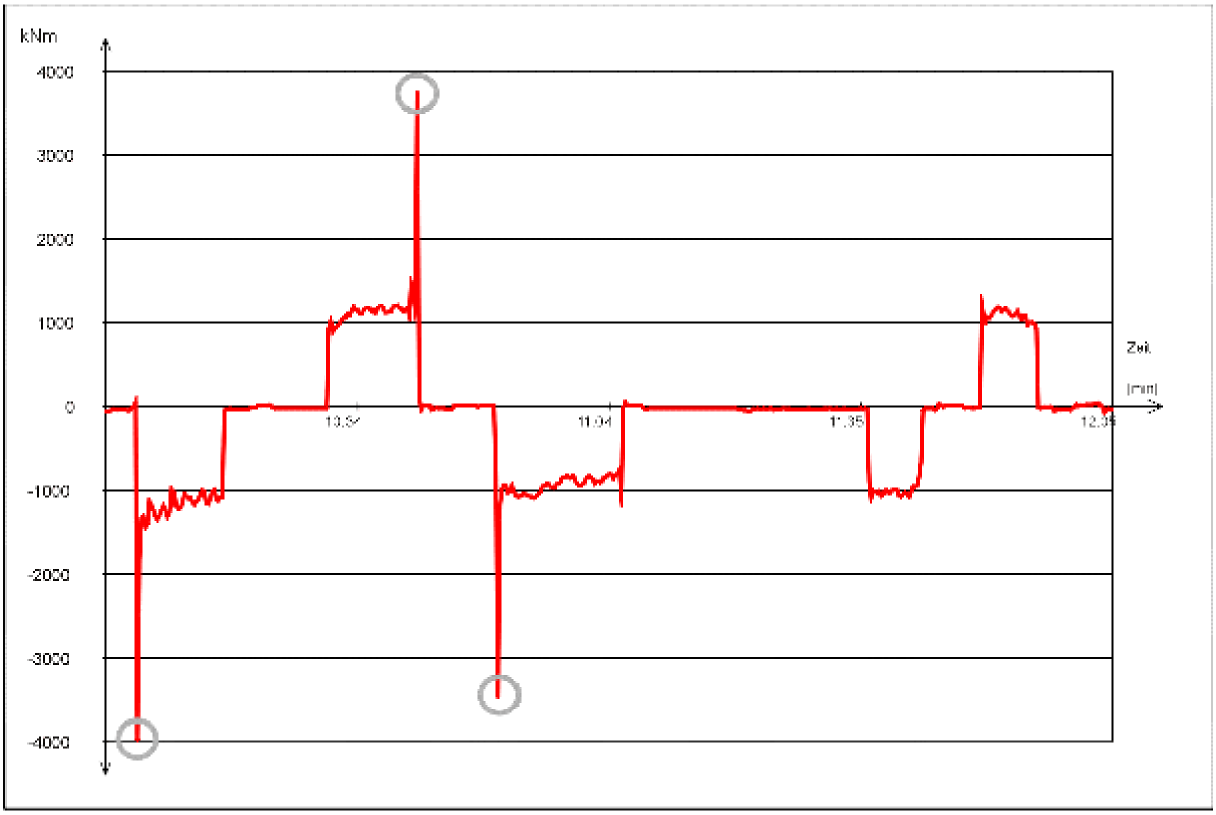

Figure 11: Excessive torque load due to the cold head of a block.

4 Summary

The paper discussed two types of quality and maintenance-related monitoring systems for rolling mills. Firstly, a vibration monitoring system to reduce the risk of gage or roll chatter and to document product quality and secondly, a torque monitoring system for process optimisation and condition-based maintenance. The practical examples presented here of the monitoring systems confirm their efficiency. The return-on-investment of the monitoring systems is less than twelve months.

Prerequisites for the success of a monitoring system in primary industries are a robust sensor technology and appropriate diagnosis algorithms, developed in close co-operation with the end-user of the tools.

5 References

/ASC98/ Asch, A..; Hohn, W.: Monitoring System for Roll Stand Drives using Strain Gage Technology. In: Proceedings of the 9th IFAC Symposium on Automation in Mining, Minaral and Metal Processing, S. 175 - 180, IFAC International Federation of Automatic Control (1998).

/FAR99/ Farkas, T.: Entwickung eines Verfahrens zur Identifikation von drehzahlproportionalen und nicht-drehzahlproportionalen Störschwingungen an Walzanlagen. Diplomarbeit an der RWTH-Aachen, 1999.

/HAI89/ Haibach, E.: Betriebsfestigkeit. VDI-Verlag GmbH (1989).

/HAN91/ Hanl, K.: Untersuchung hochfrequenter Störschwingungen an schnell laufenden Kaltwalzanlagen. Dissertation, RWTH Aachen, Umformtechnische Schriften Band 28, Verlag Stahleisen (1991).

/LOU99/ Donkle III, L.: Fifth octave chatter problem solved using vibration analysis. In: AISE Steel Technology, Volume 76 No. 11 (1999).

/MAC98/ Mackel, A.; Cerv, H; Keßler, H.-W.; Luckmann, F: Mill Diagnostic System (MiDaS) - a monitoring system with quality- and maintenance-related diagnostic functions. In: Aluminium, Volume 74 (1998).

/MAC95/ Mackel, J.; Asch, A.; Seeliger, A.: Brummerschwingungen an Walzgerüsten vollkontinuierlicher Kaltwalzanlagen: Detektierung, Verifikation, Vermeidung. VDI-Berichte Nummer 1220 (1995).

/MAC96/ Mackel, J.; Seeliger, A.: Qualitätssicherung an schnell laufenden Walzanlagen. In: Alma Mater Aquensis RWTH-Aachen (1995/96).

/MAC97/ Mackel, J.; Seeliger, A.; Georges, D.: Measurment and Diagnosis of Process-Disturbing Oscillations on Plants for Machine Condition Monitoring and Quality Control. In: Proceedings of the XIV Imeko World Congress (1997).

/MAR94/ Markworth, M.: Querwellen auf kaltgewalztem Band. In: Stahl und Eisen 114, Nr. 11 (1994).

/NES93/ Nessler, G. L.; Cory, J. F.: Identification of chatter sources in cold rolling mills. In: Iron and Steel Engineer (Januar 1993).

/ROB78/ Roberts, W. L.: Four-h mill-stand chatter of the fifth-octave mode. In: Iron and Steel Engineer Year Book (1978).

/SEE95/ Seeliger, A.; Koch, St.; Poschmann, M.: Gekoppelte Schwingungssimulation elektromechanischer Antriebe. In: VDI-Berichte Nummer 1220 (1995).