

MAINTENANCE AND QUALITY RELATED MONITORING OF ROLLING MILL MAIN DRIVES

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Introduction

Companies in the industrialised western nations mostly achieve an increase of their productivity by raising the energy input in their production plants, i.e. increasing production speed and rate. The continuous optimisation of productivity is especially important in primary industry, for instance the mining and metallurgical industry, as developing countries or those on the threshold of becoming industrialised nations have an advantage due to their potential of human and raw material resources. The increase of the power density within a production process generally implies higher standards in terms of maintenance and process control, to avoid losses in product quality and machine availability. This requires the extensive use of data acquisition, diagnostic engineering and control tools, i.e. condition monitoring.

Beneath the rolling force torque is the most important parameter in rolling. Productivity, product quality and plant reliability require a permanent even torque input into the rolling process. In practice rolling mill main drives are highly dynamically loaded components: bite impact, reversing rolling practice, torsional vibrations, cobbling etc. affect the product and the residual life time of the drive. For the monitoring of rolling mill main drives torque measured directly at the spindles turns out to have outstanding advantages over the current signal from the motor often misused for similar monitoring purposes.

The torque measuring and monitoring system presented in this paper was especially designed to the needs of heavy machinery drive trains, i.e. rolling mill main drives, and consists of a torque transducer and a computer based monitoring system. The torque transducer was developed for permanent and continuous operation at large shaft diameters with high torque load capacity and rough ambient conditions. The computer based monitoring system features besides general signal analysis functions, rolling mill specific diagnostic functions. Several application examples from practice presented in the paper will demonstrate the effectiveness and the benefits of the discussed monitoring strategies and information management.

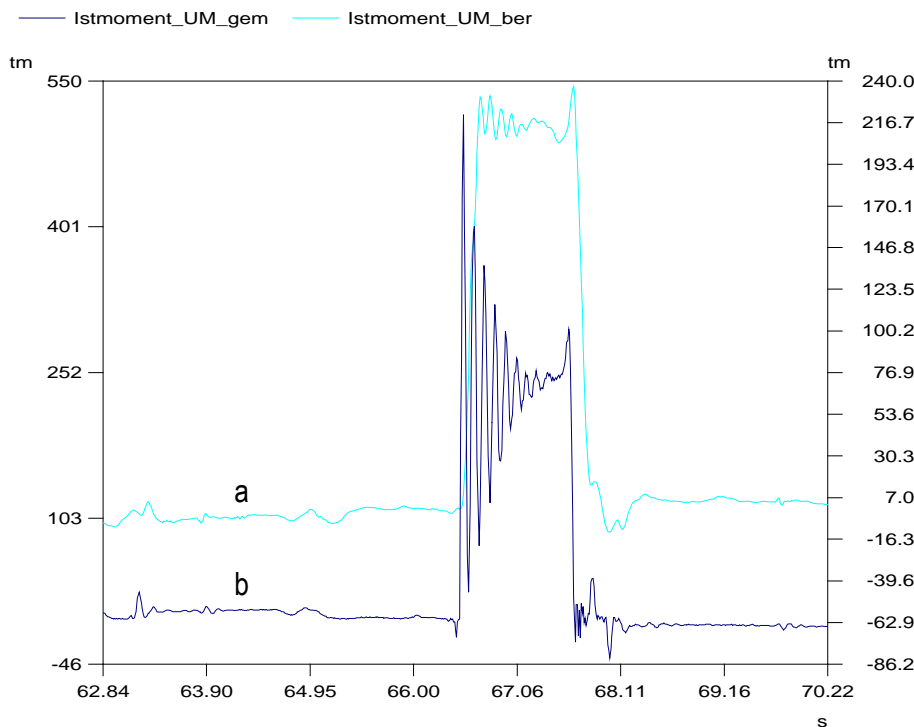


Figure 1: Motor current versus measured rolling torque at a plate mill

Torque monitoring system

The aims of torque monitoring systems for rolling mills are:

- to support condition-based maintenance strategies, i.e. the residual life time monitoring of fatigue endangered main drive components
- to control product quality, i.e. to control and avoid torsional chatter
- to document and optimise the rolling process (know-how gainings).

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.

Torque transducers

The torque sensors used in rolling mills must be very robust due to the rough ambient conditions. Figure 2 schematically shows a strain gauge and telemetry-based torque measuring system and the signal transmission to the computer based monitoring system. In Figure 3 the design of the torque transducer can be seen in detail.

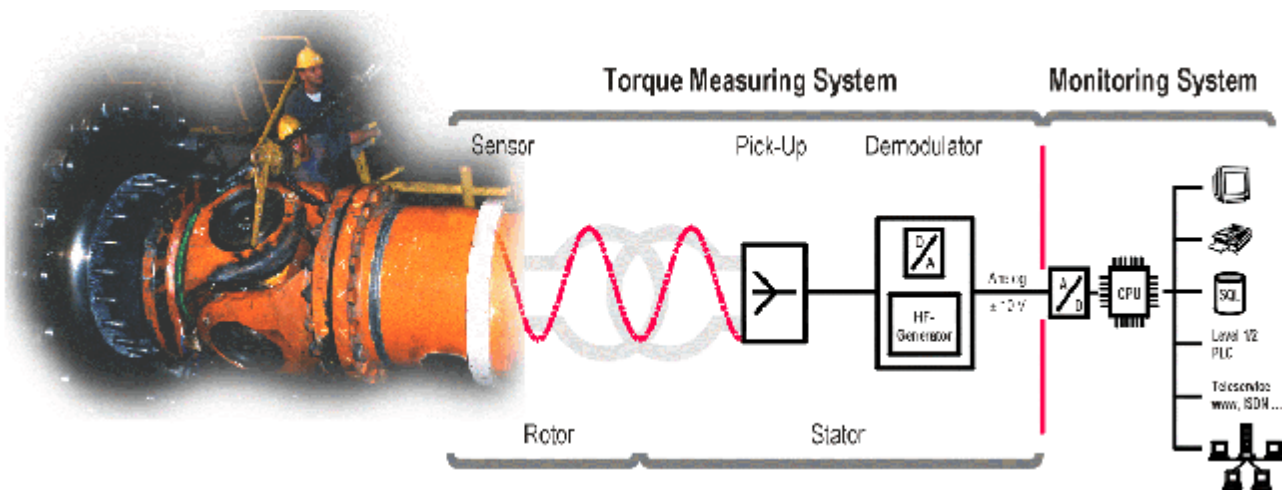


Figure 2: Strain gauge and telemetry-based torque measuring system, designed to withstand the rough ambient in rolling mills.

A sophisticated sealing system protects the strain gauge and the electronics on the shaft against water, oil or mechanical damage. Figure 4 shows torque sensors during operation in heavy water spray, installed on an hot strip mill. Figure 5 shows the same rolling mill with modernised main drives, i.e. from gear type to U-joint spindles. 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.

TTC Stator

Bracket for pick-up

Pick-up for contact-free signal transmission and inductive power supply

Cabeling and protecting tube

Demodulator (not in picture)

TTC - Rotor

Rotor Antenna

Ring with strain gauge and Telemetry system

Shaft

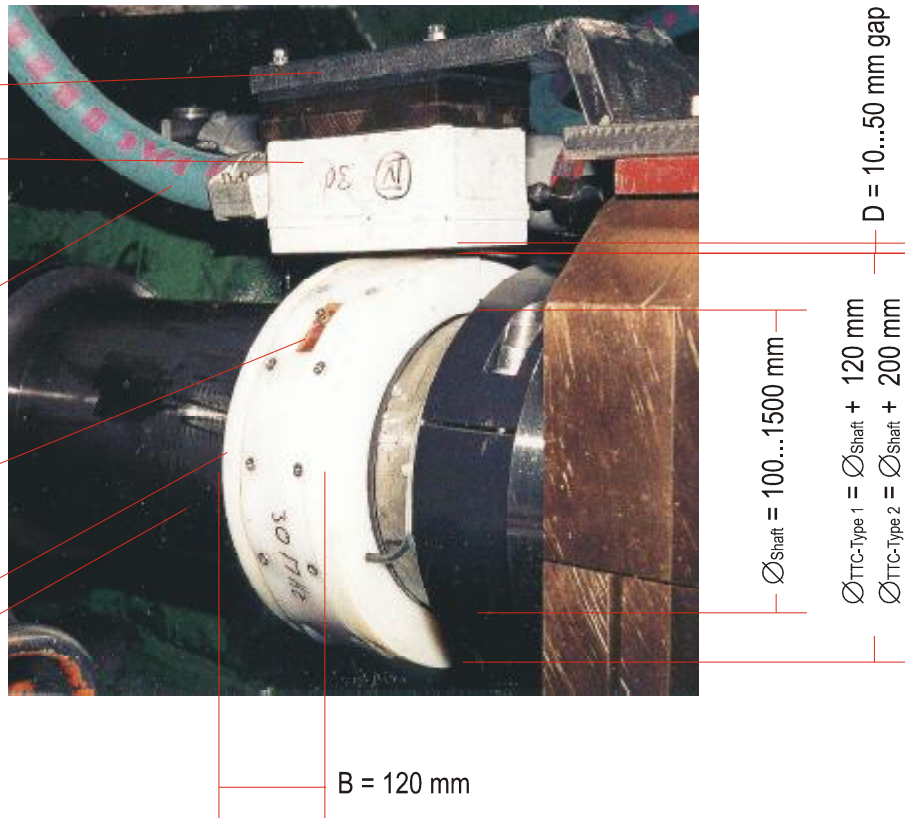


Figure 3: Design of torque transducer. Installation at a 20-roll cluster mill (Sendzimir type)

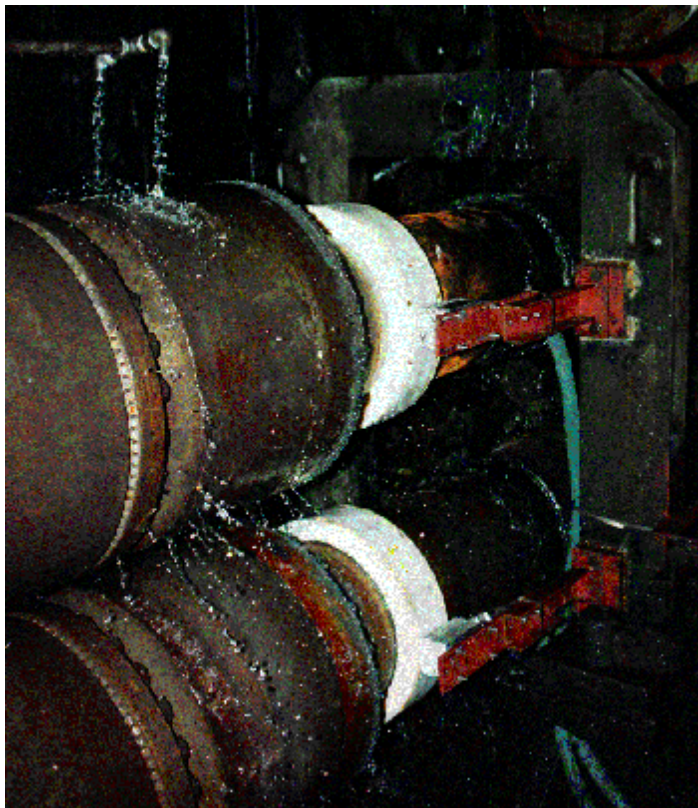


Figure 4: Torque sensors installed on the gear type spindles of a wide hot strip rolling mill.

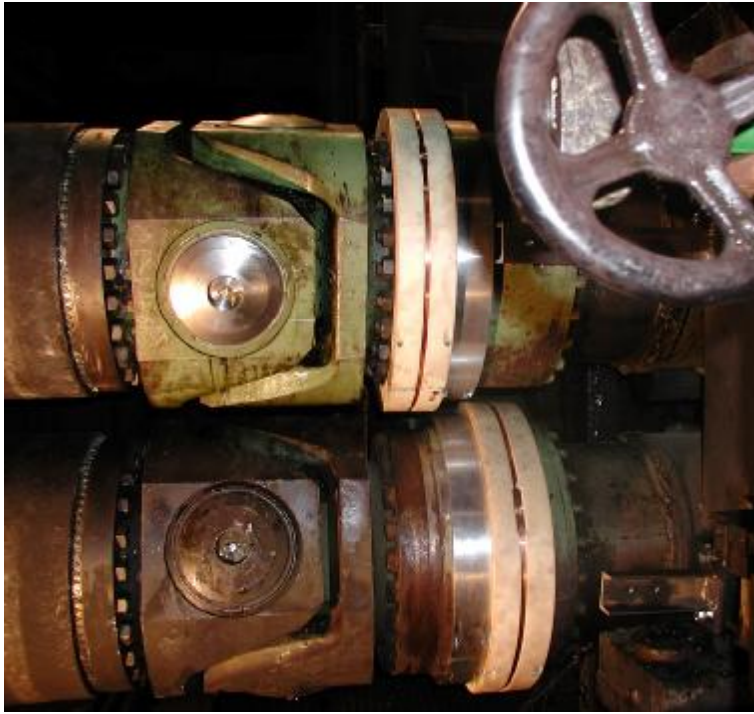


Figure 5: Torque sensors at the same rolling mill, but with modernised main drives.

Computer based monitoring system

The aims of torque-based rolling mill monitoring are the recording, analysing, visualisation and storage of data from the machine and from the process in order to:

- Support condition-based maintenance, i.e. residual life-time monitoring of fatigue-affected components, machine-based pass schedule optimisation, control of torsional vibrations etc.
- Control product quality: Roll chatter control, roll gap lubrication
- Optimise the process: torque distribution between upper and lower spindle, inter-stand strip tension control
- Document plant operation, shut-down periods, commissioning of new plant components, modernisations a.o.
- Gain know-how: optimisation of rolling speeds, operating points etc.

To achieve the aforementioned goals, the software should have the following features /ASC98/:

- Recording, display and storage of torque and additional plant signals
- Classification algorithms for a residual lifetime estimation based on fatigue analysis /HAI89/
- Online and offline display of time signal, frequency spectra and cumulative frequency spectra
- Monitoring of limit values / curves in time and frequency domain
- Transient triggering (alarm signal storage with pre- and post-history)
- Storage of trend data
- FIFO-like data storage in an SQL database for maintenance-free long-term evaluation of data
- Intelligent report generator for automatic reporting to the decision makers
- Tele-service enhanced

Along with the measured torque, additional plant signals, for example rolling force, mill vibration, block or coil temperature, rolling speed etc. are monitored. Data can be acquired as analogue signals which are connected to A/D data acquisition plug-in boards or alternatively via digital telegrams directly from the PLC and then analysed using automatic monitoring functions and intelligent algorithms. Standardised communication interfaces (i.e. ethernet, TCP/IP) allow the connection to client networks and to the machine control system or process computer. Monitored signals can thus be stored according to plant and process information, which allows correlation analysis and data trending, i.e. in relation to product ID's, material specification etc. This interface can also be used to send measured data or trend values from the torque monitoring system to the process control system.

The visualisation of data and information from monitoring system should be two-fold:

1. Comprehensible and easy-to-read information displayed in the operator stand, which allows a fast feed-back in case of identified trouble, for example roll chatter.
2. Fully graphic visualisation of all signals and monitoring results in order to allow engineers to perform in-depth analysis and data mining

Figure 6 shows the design of a torque-based rolling mill monitoring system with additional sensors for online roller bearing diagnosis, temperature and roll chatter monitoring.

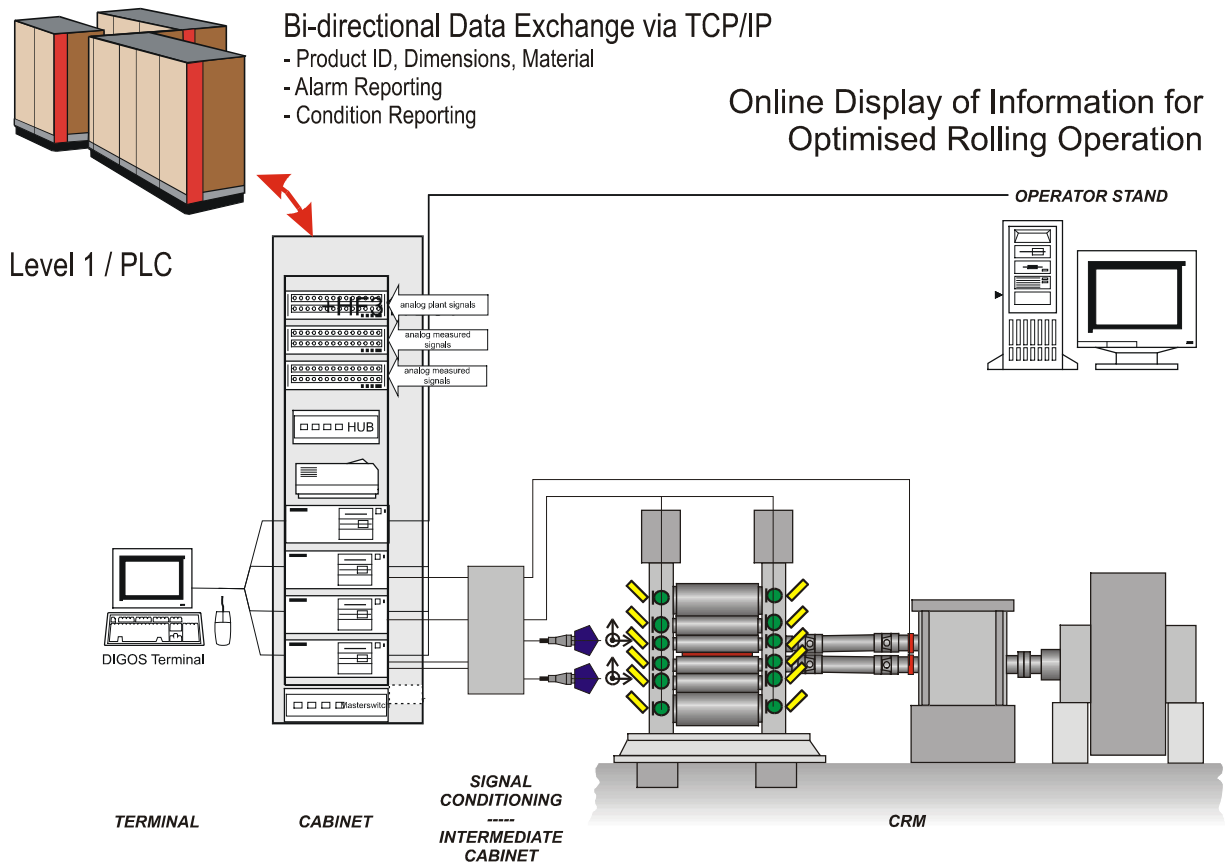


Figure 6: Online Machine Monitoring System

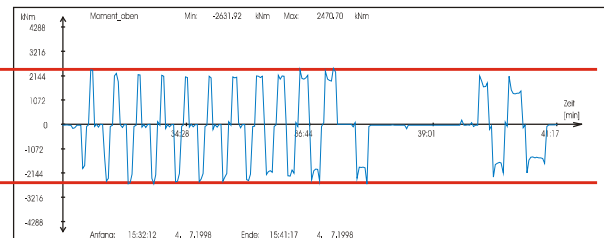
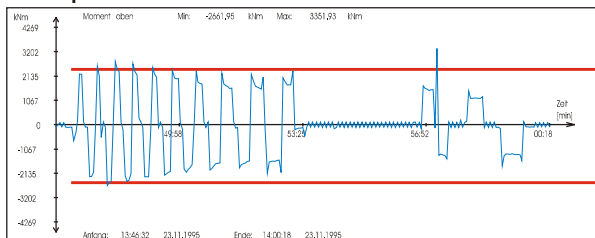
Examples of practice

The results of some examinations on different types of rolling mills illustrate the installation, use and benefits of torque monitoring in rolling mills.

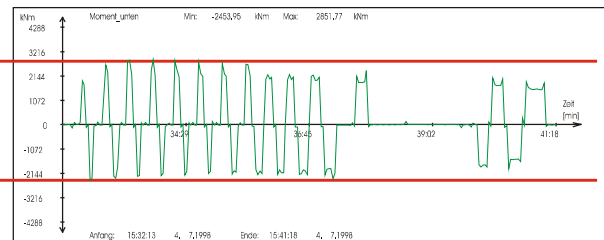
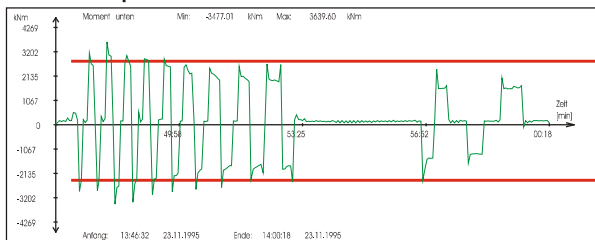
Machine-related pass schedule optimisation

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 7 (reversing roughing mill for aluminium), the original pass schedule foresees 23 passes for a specific material. Although this material represents only a small percentage of the annual 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.

TOP Spindle



BOTTOM Spindle



Before Optimisation of Pass Schedule: After Optimisation of Pass Schedule:

- | | |
|--|---|
| <ul style="list-style-type: none"> - 23 Passes - Percentage of Yearly Tonnage: 5 % - Percentage of Drive Wear / Fatigue: 30 % | <ul style="list-style-type: none"> - 27 Passes - Negligible Loss of Production Time - Percentage of Drive Wear / Fatigue < 10 % |
|--|---|

Figure 7: Machine-related pass schedule optimisation leads to lower torque loads.

Torsional vibrations

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 8. The heavy torsional chatter which occurs in the middle of the pass marks the surface of the block and causes severe damage (fatigue) 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.

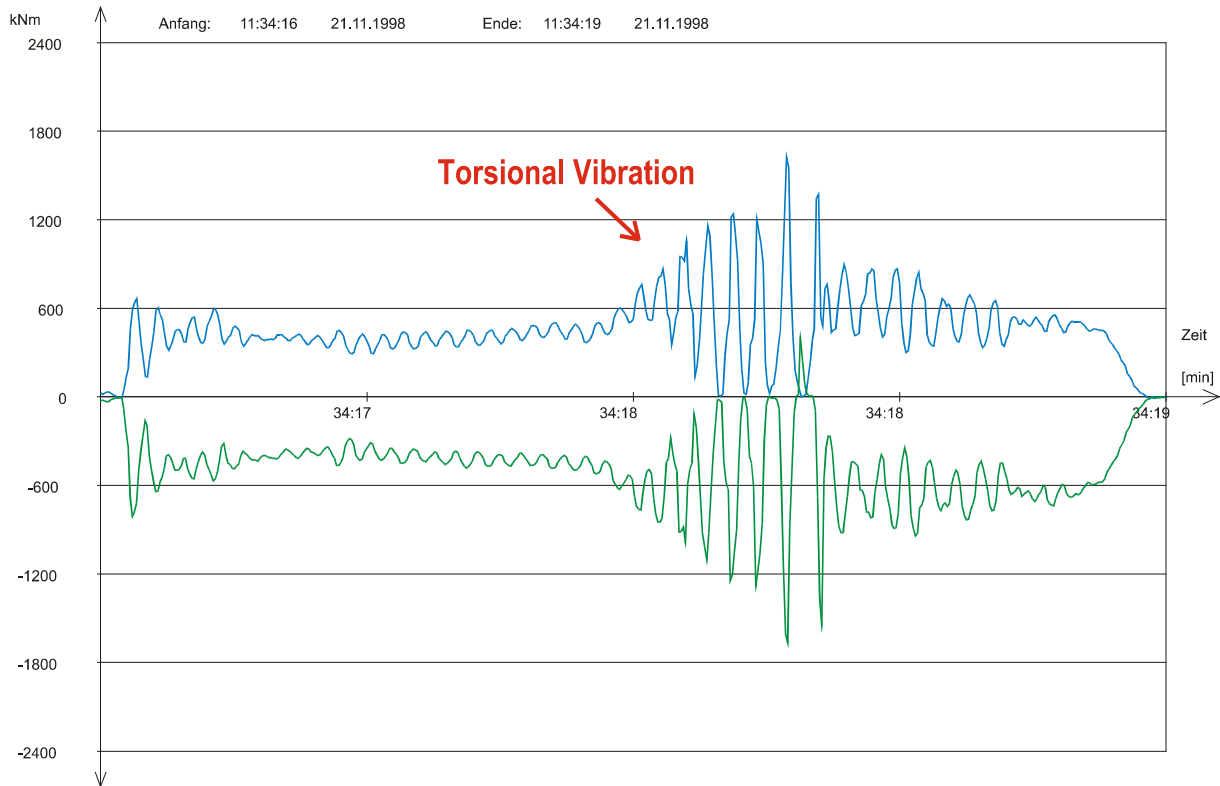


Figure 8: Heavy torsional chatter in the main drive of a roughing stand (steel)

Bite-impact control, cold tail

The bite impact provides the most important contribution to the fatigue of rolling mill main drives, i.e. the dynamic overload resulting from the rotating mass-spring system (motor-gearbox-rolls) and the entering of a block or a strip into the roll gap. The bite impact is characterised by the relation between the peak value of the torque at bite impact and the mean torque value during static rolling. This relationship is quantified by the TAF, i.e. the Torque-Amplification-Factor (Figure 9).

As already mentioned and shown in the introduction of the paper it is erroneous to use the current signal from the motor to reproduce the torque load on the spindles. This is only valid for static rolling, i.e. in cold strip rolling mills. The motor current is not representative for the mechanical torque transmitted by the rolling mill main drive, as illustrated in Figure 10.

A 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. A threshold value monitoring with alarming reported to the operator can help the recognition and cutting-off of such processes.

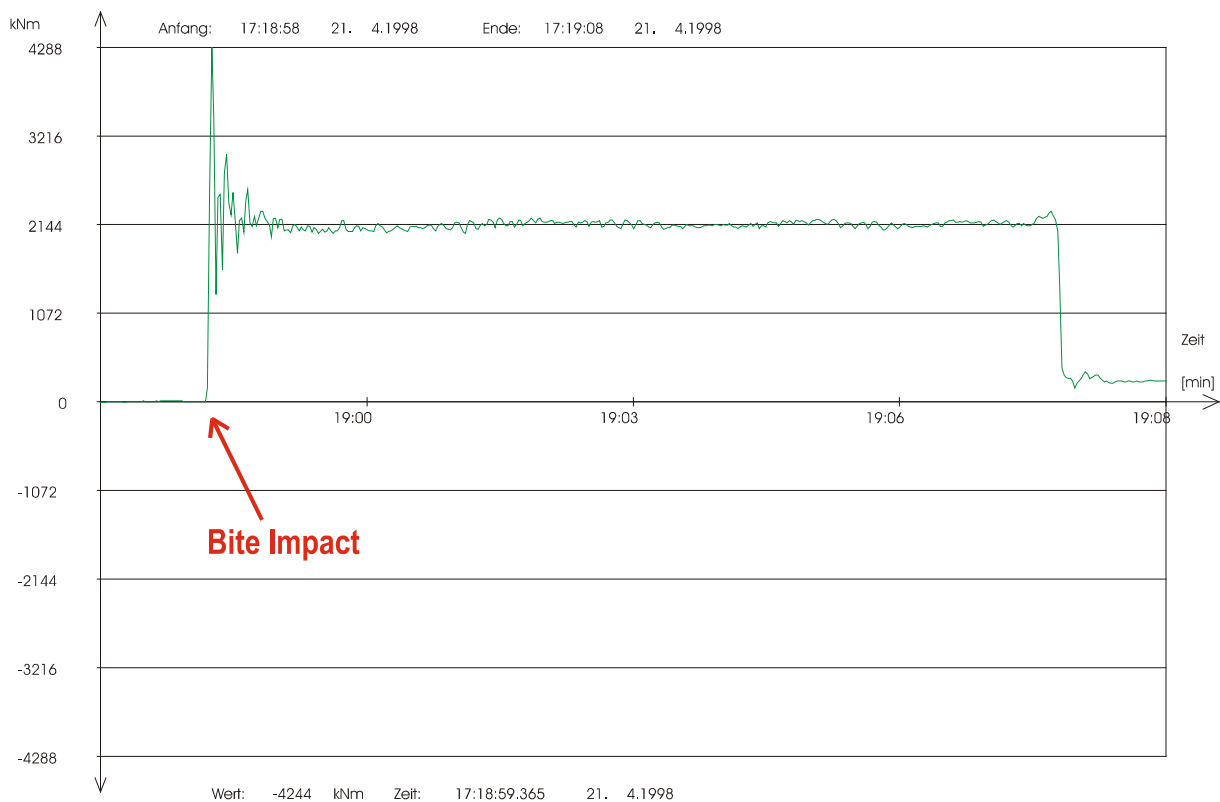


Figure 9: Bite impact and TAF

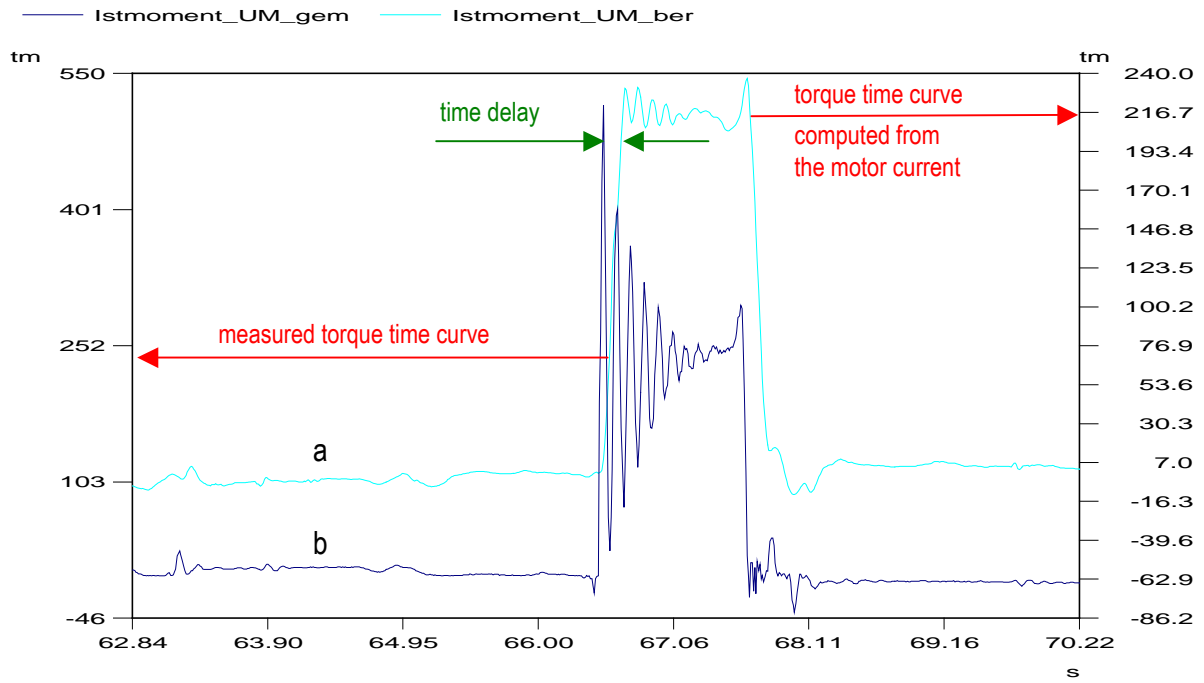


Figure 10: Torque measured on the upper rolling mill main drive spindle (b) vs. torque computed from the motor current (a)

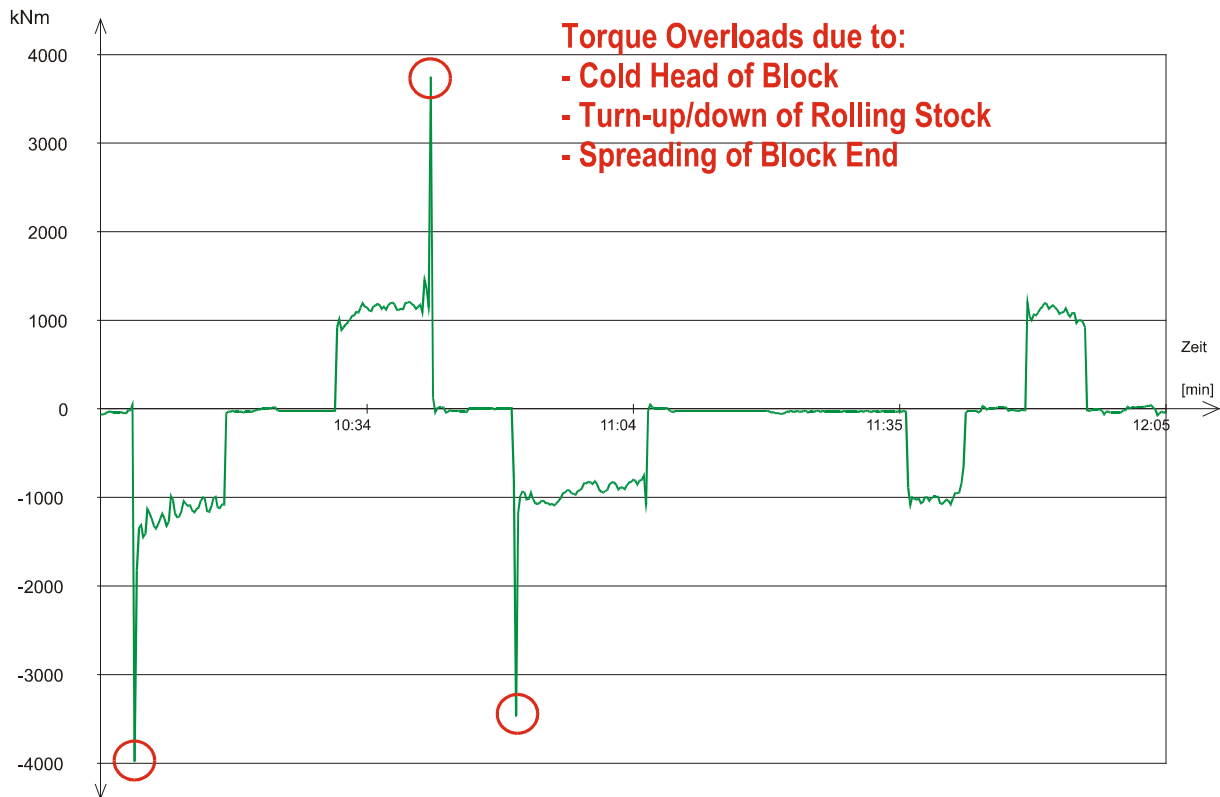


Figure 11: Excessive torque load due to the cold head of a block.

Documentation of the rolling process

Figure 12 shows the typical pre-history of a cobble stop caused by adverse operation. After the 7th pass the roll gap is not adjusted. The 8th pass shows a very low torque load, i.e. the elastic deformation of the block. For the 9th pass the operator sets the prescribed target value, i.e. including the missed reduction of pass no. 8. As a result it takes 3 trial to pass the block trough the rolling mill. The monitoring not only documents the severe overloads but also a careless rolling operation.

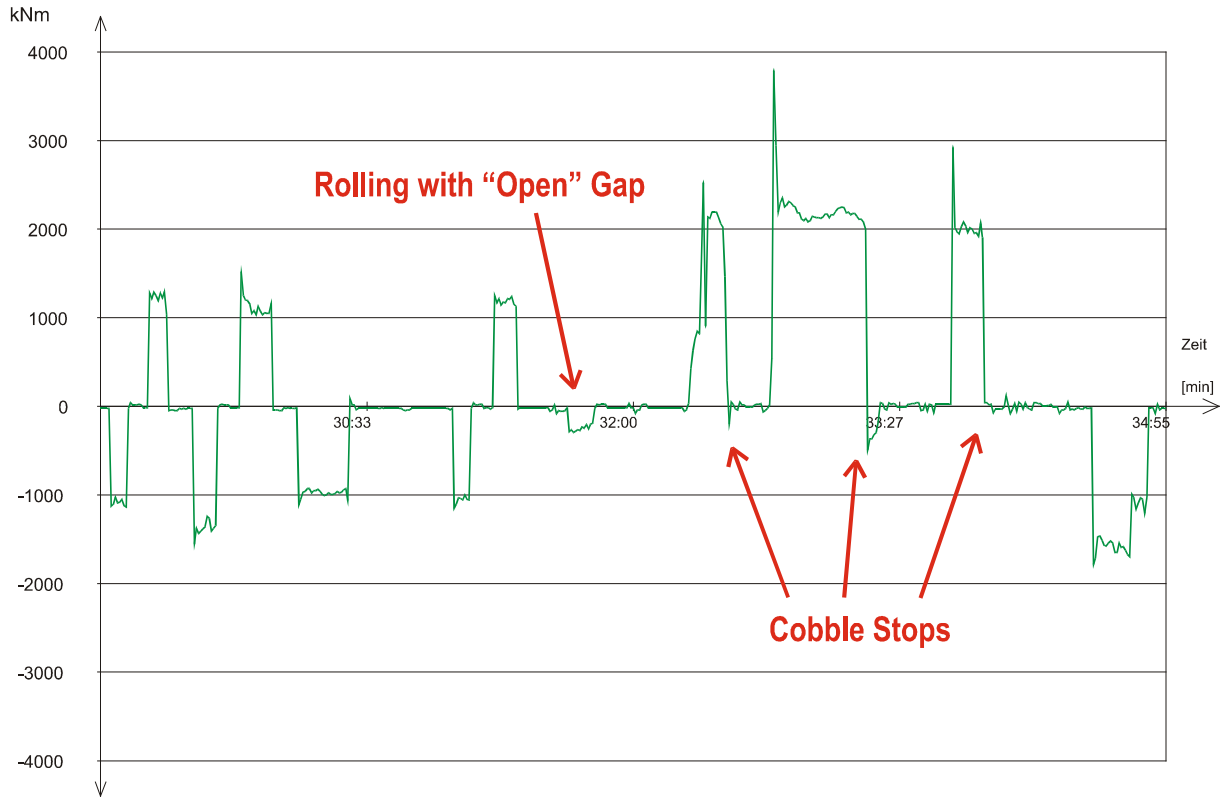


Figure 12: Pre-history of a cobble stop

Strip lubrication

As a last example of practice Figure 13 shows the effect of uneven torque load distribution between the upper and lower roll. At gearbox driven roll stands uneven torque distribution is totally invisible to the motor current, which means that the measurement of torque on the main drive spindles is for example the prerequisite for an exact trimming of the strip lubrication.

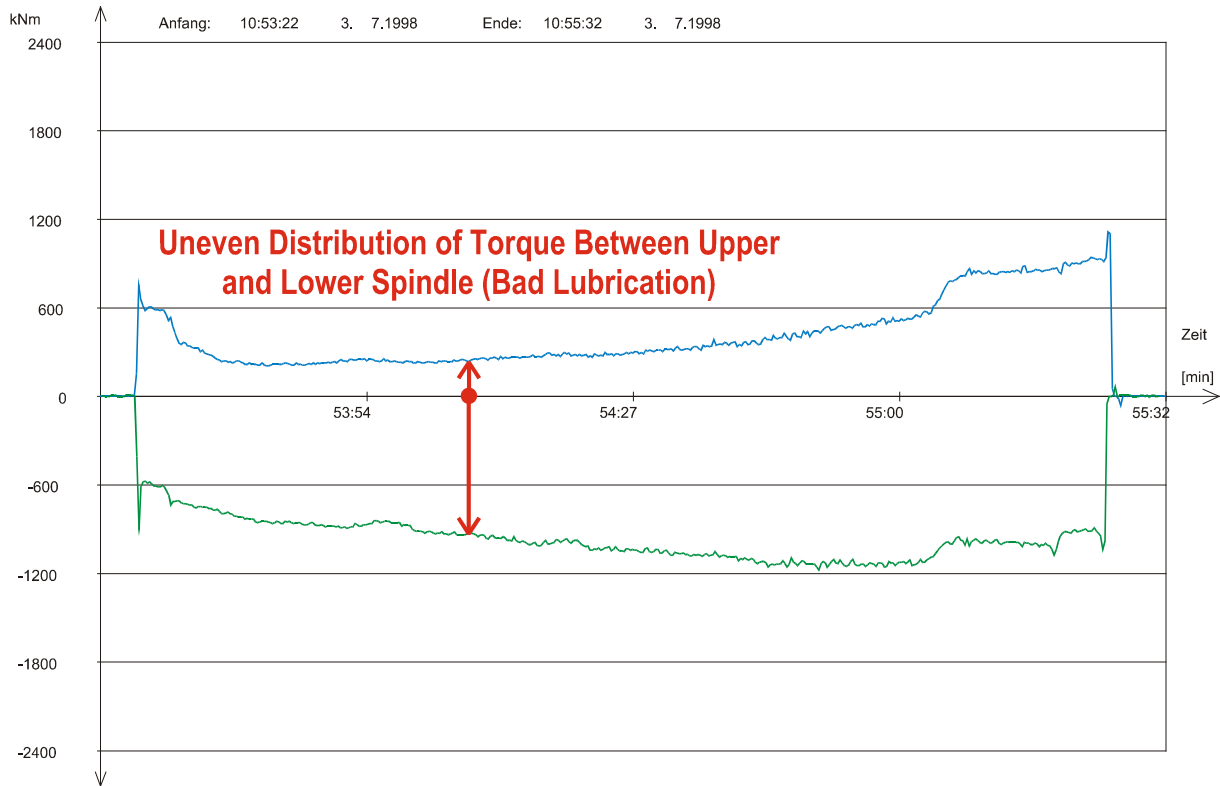


Figure 13: Distribution of torque between upper and lower spindle

Summary

The paper discussed a torque monitoring system for process optimisation and condition-based maintenance. The torque transducer was especially designed for rough ambient conditions, thus enabling a maintenance-free permanent operation in rolling mill environment. The computer based monitoring system uses torque and additional plant signals for a rolling mill main drive specific signal analysis.

The benefits of torque monitoring at rolling mill main drives are to support condition-based maintenance strategies, to control product quality, to document and optimise the rolling process.

The practical examples of the monitoring system presented in the paper:

- Maintenance-oriented pass schedule optimisation
- Monitoring of torsional vibrations
- Bite impact monitoring
- Torque versus motor current comparison
- head of block monitoring
- Cobble-stop monitoring
- Strip lubrication control

These few examples of operated torque monitoring confirm it's efficiency. Most of the applications showed a return-on-investment period of less than twelve months. Prerequisites for the success were the robust sensor technology and appropriate diagnosis algorithms, developed in close co-operation with the end-users of the tools.

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