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CONTROL PROCESS FOR A COLD ROLLING MILL BY VIBRATIONS AND TORQUE

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ABSTRACT

This paper shows the results of researches regarding a system of monitoring and other parallel systems for diagnose used in a cold rolling mill. The first system (with specific sensors) is an online vibration monitoring system for control on-line the sheet quality and mill maintenance in relation with diagnostic functions. The second system is used to monitor the torque and to measure the mill parameters as well (the force, the mill speed, the gap between work roll etc.). This system is a part of the integrated control process.

Keywords: Cold rolling mill, torque, vibration, chatter, quality control, maintenance

1. INTRODUCTION

In order to obtain a profit, it is important for economic agents to increase their productivity by using a flexible production line with diminished losses and by fully exploiting their human and material resources.

The extension of condition monitoring and process control is to reduce maintenance costs, increase productivity and improve product quality [1]. We study the vibration in the most important parts of cold rolling mills. This phenomenon causes severe damage for the mill machine and strip quality (Fig. 1).

Fig. 1. Strip faults, due to rolling mill vibration

The integrated control process is made to analyse the vibrations which are produced on the work roll chocks and backup roll chocks.

The noise and chatter signals are carried out in the time and frequency range. The noise has to be eliminated to obtain reliable strip quality in conformity with predicted dimensions.

On the long term we can create a database used to make a comparison between an initial signal and a work signal and finally to archive a quality standard for each strip. In a parallel system we made a comparison between the initial torque and the torque during the rolling process.

The purpose is to diagnose [2] the state of the mill machine and predict when some of its parts can have problems in work.

The accuracy of the sheets thickness (texture or surface roughness) is important for the beneficiary of this product. In work conditions, vibrations or oscillations may occur, which again causes gauge chatter or chatter marks on the rolling sheet.

The gauge chatter consists of periodical faults in the 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. The amplitude and wave length of periodical strip faults depend on the vibration system and the vibration frequency.

2. ON THE VIBRATIONS SYSTEM

According to the incitation system there are free vibrations which occur when a single impulse (the rolling stand or parts of it oscillate with their own natural frequency) affects the oscillatory systems.

On the other hand, there are excited vibrations in the rolling stands determined by the damage that exists in some parts of the rolling mill machine.

In this context, there are vertical vibrations [3] from the roll stand (1-16 Hz.), torsion chatter of the main drive (5-20 Hz.), interspaces chatter or third-octave chatter (100-300 Hz.), roll vibration or fifth-octave chatters (500-700 Hz.).

In practice, the differentiations of interfering frequencies into those which are proportional to the speed and those which are not are the first step in describing the phenomenon of vibration and its manifestations.

Figure 2 presents the results of gauge chatter on a 5-stand cold rolling mill in terms of roll stand vibrations.

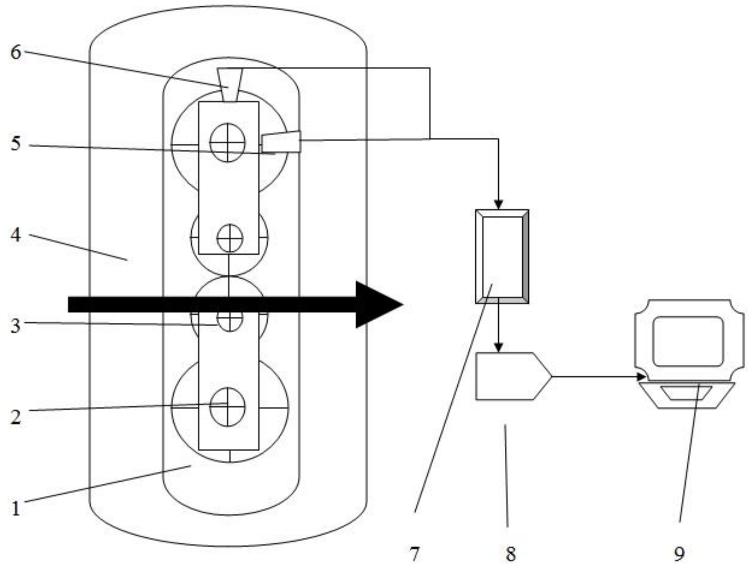

Fig. 2. Schedule for the rolling mill parameters recorded: 1 - work roll; 2 - rolls support; 3 - backup roll; 4 - mill stand (frame); 5 -horizontal accelerometer; 6 - vertical accelerometer; 7 - signal preamplifier; 8 - signal filter; 9 -process computer

Some of these manifestations are the eccentricity of the rolls and tooth error drive irregularities, due to the displacement of the shaft roll gap fluctuation, and the chatter marks due to the excessive free motion.

Experiments were performed on 3, 4, 5 frame of the rolling mill (scheme of accelerometers placed like in figure no. 2) because they display the highest values of displacements, acceleration and frequency vibrations and that, in fact, represents the latest stage in the achievement of the finished product. This schedule is used for automatic online diagnosis of the vibration status of rolling mills.

The measurements were performed on 22 rolls, after which the change was made on the working cylinders of the five stand of the rolling mill.

The magnitude and frequency of vibrations are influenced by the speed of rotation of the cylinders, the rolling force, the tension between frames, the emulsion used – the characteristics of vibrations and they were recorded during the mentioned periods of time. During the measurements campaign, we have also measured and recorded the functionary parameters for the five stand of tandem (table 1.a) the rolling forces, tensions in the band and speeds rotation of cylinders - for one of the rolled rolls.

The rolled material was steel band of 12 Ust (of 1623) having: Nominal thickness of 1.88 mm (entrance in tandem); 0.362-0.408 mm in output, chemical composition and mechanical characteristics of the table 1.b.

Table 1.a

Frame	1	2	3	4	5
Rolling force x10^4N	1250	1150	1100	1050	1000
Rotation speed of the working cylinders, rot/min	300	470	580	690	880
Tension between the frames x10^4	1-2 40	2-3 32	3-4 19	4-5 11	

Table 1.b

Chemical composition [wt %]					
C	Mn	Pmax	Simax	Smax	Al
0.11	0.45	0.035	0.050	0.040	Min 0.015
Mechanical properties					
Rm (N/mm^2)		Flow’s limit $R_{p0.2}$ (N/mm^2)		A_5 %	
240		270-370		34%	

3. THE TYPE, LOCATION AND RECORDING OF VARIABLES

Here follows a set of measurements regarding the amplitude, the accelerations, the frequency spectrum, and the vibrations occurred in the process of bands rolling mentioned – in stands 3, 4 and 5 – of the tandem rolling mill. The measurements were made on the support of lower and upper cylinders, on the operator side.

The measurements were made with transducers placed upright, horizontally and axially on cylinders bearings support for shareholders and operator.

From the analysis made one can conclude that the greatest value for movements, speed, and acceleration were recorded at 3, 4, 5 stands of the rolling 0mill.

For the frame number four the value of measurement recorded as follows:

3.1 Measurement of stand displacement

The maximum displacement, measured on the cylinder upper support (operator-action), was 355 x10^{-6} m, 370 x 10^{-6}m.

The maximum displacement, measured on the lower support of the cylinder (operator-action), emphasized lower values, meaning 36x10^{-6}m and 178x10^{-6}m.

After comparing these data one may notice that the highest value of movements was on the upper support of cylinder (Action part). This is due, perhaps, to the existence of some vibrations coming from the chain of cinematic shareholders.

3.2. Measured and recorded accelerations

The measured and recorded maximum of acceleration was about 4m/s^2, from the action part and from the operator was about 3m/s^2.

3.3. Measured and Recorded Frequencies

The frequency spectrum (operator) is presented for the block of lower and upper cylinders and the graphs of the frequency spectrum for the block of upper cylinders whose values were in the range of 100-300 Hz.

The same kind of measurements, namely: displacement, acceleration and frequency, were performed on the upper and lower support of cylinders (the side of shareholders and operator)

3.4. Measured accelerations in the stand number three.

The maximum value was about 2m/s^2, which represents about 50% of the acceleration value in the stand number four.

3.5. Measured accelerations in the stand number five

The maximum recorded acceleration was about 2.5m/s^2 so it is situated between the maximum values from stand number three (1.6m/$s^{2)}$ and stand number four (4m/s^2).

4. RESULTS INTERPRETATION

On the basis of records and measurements made, it results that:

1. The highest amplitude of vibrations has been emphasized in 4 frame (action side), compared with frames 3 and 5. Accelerations and frequencies had the greatest values from action sides, for all three frames (3, 4, 5)

2. The vibrations caused the appearance of some wavy parts on the surface band (rolls 14 and 16; thickness output 0.37; width 1660mm) – for stripes 20-40 mm thick before milling. After rolling a number of 22 roll strips, the cylinders in the stand number five were changed.

3. Traces and printings belonging to these cylinders are observed – before the change of working cylinders – on the surface of the last 5 rolls strip.

5. Analyzing the spectra frequency related to 3, 4, 5 stands of the mill, two maxima were noticed, respectively:

- frequency in range of 100-300 Hz that represents characteristics for damage of positioning system interspaces, for the quality of cylinders surface, for lubricant and, the last but not least, for variations of cylinders rotation speed;

- frequency in range of 500-800 Hz that may generally show a stress-related wear of support cylinders, of their bearings (with tolerance in the size).

Areas of graphs frequency – related to the 500-800 Hz range – are not significant for the value of vibrations of magnitude compared to the area related to the 100-300 Hz range.

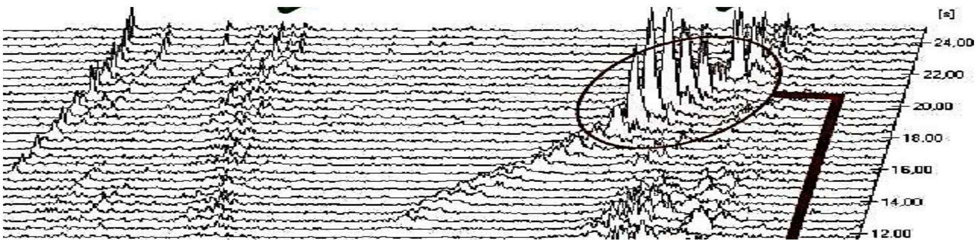

Fig. 3.Vibration recorded from drive side (right with red line) and operator side (left side) [5]

This can lead to the interpretation of surface defects that occurred due to some reasons above-mentioned but correlated with the state of wear rolling mill in general, the working cylinders in particular, and the bearing tolerance.

During a temporary measurement the vibration initiating roll stand had to be identified. The results of the analysis showed that stand number five initially caused the gauge chatter. The vibrations propagated 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.

Finding the speed-proportional excitations is of crucial importance, as they allow the detection of the original, mechanical causes of the excitations.

However, the analysis of cumulative [4] spectrum is often time consuming as the excitation effects depend on many strip parameters (material, width, thickness etc.), and thus do not appear during each pass.

At speeds between 600-1250 m/min, the rolling and the vibration frequencies measured not exceeding 450Hz, we did not register print and sudden wave variations in the thickness of the rolling strip.

At vibration frequencies between 450-1150 Hz we noticed, in the case of wave surface bands with step between 2-40 mm, a pronounced wear of the work-support cylinders and their bearing.

Following the experiments carried out during 2010-2011 at a number of rolls rolled over in 2000 rolls strip, consisting mainly in measurement and analysis of the vibrations, the following range of common characteristics was established:

- vibrations in the range of frequencies 5-90 Hz, corresponding to couplings, gearing, gear box, flaws in the camps;
- vibrations in the range of 125-300 Hz frequencies, corresponding to common lane that roll, games in interspaces positioning system, wear in the camps, Lubricant used.
- vibration frequencies in the range of 500-980 Hz, related to wears emphasized the decks.

The optimized 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. The heavy torsion chatter which occurs in the middle of the pass marks the surface of the block and causes severe damage to the drive. A process optimization may be carried out if such events are recorded and analyzed. In this case, the lubrication system was improved.

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.

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 gauge or roll chatter and to document product quality and secondly, a torque is monitoring system for process optimization and condition-based maintenance. In Figure 4, the authors show a strain gauge for torque measuring.

The authors obtained results for different types of rolling mills that illustrate the benefits of monitoring systems in cold rolling mills. The first example shows a machine-related pass schedule optimization for the mill machine analyzed.

Experiments in tandem operation revealed: the tendency of growth of vibrations amplitude at high speeds lamination, which appears as a result of the increase of the speed of rolling with about 50% per rolling mills, registered a vibrations magnitude growth of around 35% per frame.

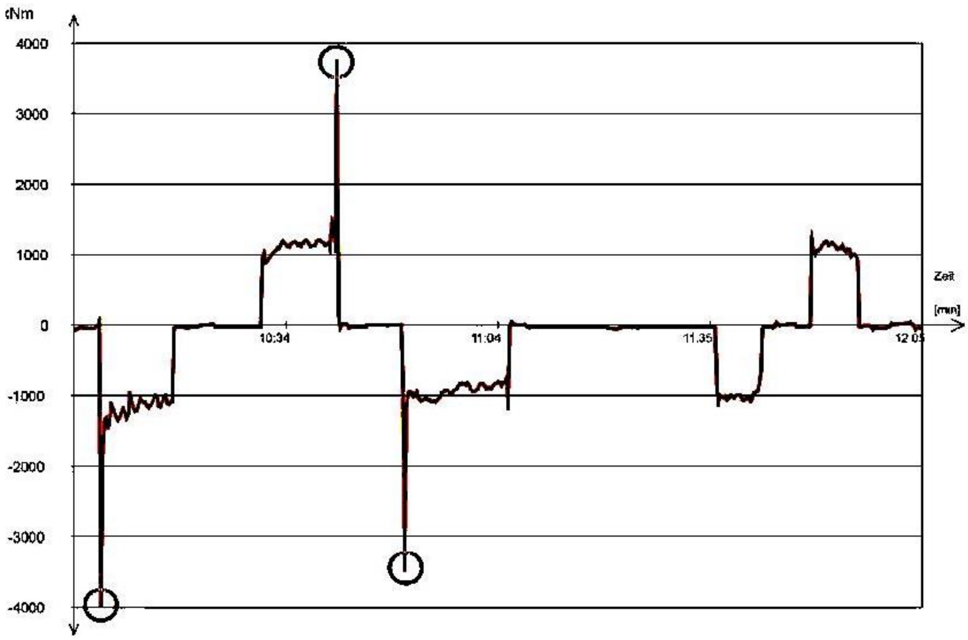

Fig. 4. A recorded of coupling torque [8]

On the other hand, the band widths with narrow and heavy sea manifest the same tendency of increasing amplitude vibrations, unlike bands with great width and thickness, where the effect of damping vibrations is considerably higher [6]

The torque sensors used in rolling mills must be very robust due to the rough ambient conditions.

Although this material represents only a small percentage of the yearly overall production at this mill stand, the arising torque loads damage components of the universal joint at a roughly ten times higher percentage in terms of residual lifetime.

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.

The problem resulting from all research is the importance of analyzing the conditions for scientific running of rolling mills, the identification and quantification disturbing factors and finally, modern design, for increasing resistance, reliability, reduce consumption, ensure continuity processes and product quality finished.

All this led to the development of a general concept for the establishment of dynamic influences on complex machinery and quantification of the dynamic forces [9].

The modern analysis of the tensions leads to the design with a minimum of approximation and uncertainty of sub-assemblies of equipment.

One of the main measures in the design and optimization systems for machinery important action is to determine the size of dynamic moments that may occur during operations.

It is necessary to develop models that combine aspects of dynamic mechanical and electrical systems and through computer simulation to provide functionality and efficiency as well as deficiencies in the operation [10].

The most suitable measures to reduce the load in the stage design of the rolling tandem and its cinematic and constructive schemes are:

- the choice of a rational cinematic scheme without any weak joints;
- the establishment of real physical processes that occur in the control and working equipment taking into consideration the mass distribution and the tolerance in the systems under scrutiny;
- the use of computer modeling to determine the optimal parameters of cinematic and dynamic simulation;
- rational location of the action mechanisms of transmission without long or complicated cinematic chains.

5. CONCLUSIONS

A major conclusion of the investigation on the basis of which some research contracts have been concluded and completed with ARCELOR MITTAL S.A. - is a pressing need for the reduction and possible elimination of vibrations in order to increase reliability of all the rolling mills and the production of endless bands according to international standards [11].

If we do not take into account the effect of varying tasks, and in particular of the dynamic errors appearing while dimensioning the machinery components, repercussions can appear regarding the rolling mill reliability and production quality.

The research lead to the following conclusions.

1. Under the action of variable tasks (from both inside and outside the system) the cinematic chain may experience distortions, such as the variation of the forces and resistance generated by the materials from which the components are made, as a result of the phenomenon of fatigue. This is the most frequent cause of the deterioration of equipment subassemblies.

2. The main sources of rolling mill load are the dynamic forces that appear when starting and braking; the tolerances that appear in the working joints of the cinematic chain, the wear of its subassemblies and its faulty execution and assembly.

3. For a 1700 mm five frame cold rolling mill tandem the dynamic couples had measured values that exceeded the calculated/theoretical ones with about 17% for the frames I and II, and approx. 23.5% for the frames III, IV and V. These differences are cause by the following: the shock due to the clamp lane between rollers, the tolerances due to the training chain components wear, inadequate emulsion, tolerance related to the positioning system, the wear of the deck cylinders and the hardness of the band.

4. In terms of sharing dynamic effects for the studied tandem, the authors can claim that the most important dynamic couples in the first and second frames are mainly due to

the positioning system and are also wear-related, while for the last frames of the mill (III, IV, and V) they are caused by the cinematic chain of the motor-couplings, bar-coupling, as well as by the type of emulsions and the frame alignment.

5. In order to optimize the thickness reduction scheme, the speed, the tensions, to obtain a maximum uniformity of the thickness along the rolled strip and in correlation with a control system for rolling vibrations of the tandem (by continuously adjusting the system of speed-tension scheme), we designed a mathematical model covering all motion and operating parameters.

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