BACKUP ROLL BEARING TEMPERATURE MONITORING ON A TANDEM COLD MILL *

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Abstract
The Tandem Cold Mill is composed by stands with rolls positioned so that the rolling force can be transmitted to the strip being processed. Due to the mechanical stresses inherent in the process, the roll bearings are heated and are equipped with lubrication and cooling systems. Nevertheless, there is the challenge of continuously monitoring the temperature of the bearings, which would allow preventive intervention in case of overheating. This paper presents an in-house solution to temperature measuring system applied to the backup roll bearings of a continuous Tandem Cold Mill. The system uses Zigbee technology and is integrated with the main control system, allowing early diagnosis of bearing heating and proper intervention. Results and features of the system are discussed.
Keywords: Tandem Cold Mill; bearings; Temperature monitoring.

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1 INTRODUCTION

The Tandem Cold Mill (TCM) is composed by stands of rolls that rotate at different speeds and apply tension in the steel strip in order to reduce their thickness.
A pair of rolls has direct contact with the strip and is used to apply speed and force required for traction and reduction of thickness. These are known as work rolls (WR) and have small diameter compared to the other rollers of the stand.
For transmission of the rolling force from actuators cylinders and the work rolls, larger diameter roll known as backup roll (BUR) are used. Some rolling mills also use intermediate rolls between work roll and backup roll. Figure 1 shows a simple arrangement of a four stand TCM with 4-high stand configuration, one of the most used in steel strip mills [1].

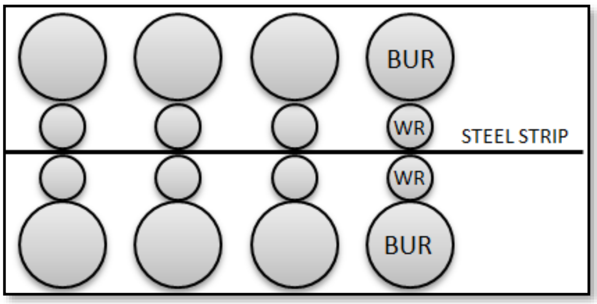

Figure 1. 4-High Tandem Cold Mill

BUR are arranged in chocks which may be built with rolling bearing or oil film bearing.
The oil film bearing has been widely used in cold strip mills since the 1930s for its ability to operate where high speeds and high pressure are required on the bearing. Since the 1980s, improvements in rolling bearings have also allowed their application in cold rolling mills [2]. To oil film bearings, a dedicated oil system ensures constant oil flow into the bearing, and thus the hydrodynamic action required to maintain the oil layer between the bearing sliding parts [3].
The rolling bearings are mounted with a certain amount of oil to ensure lubrication and have an oil-air mixture lubrication system that maintains positive pressure inside the bearing and adds a small amount of oil.
The reliability and lifetime of the BUR and its bearings is very important considering it is an expensive asset and relatively complex maintenance equipment. Failure analyzes on these components and their causes are studied by suppliers and customers and are important in preventing new failures, which cause production disruption and high repair costs.
Several factors are indicated as causes of bearing failures, such as assembly problems, lubricant quality, excessive load, clearance, excessive temperature, and so on [4]. Besides good maintenance and assembly of the bearings, some conditions, such as vibration and temperature, can be monitored to help on preventive detection of bearing failures.
This paper presents an on-line temperature monitoring system developed for the BUR bearings of a four stands TCM equipped with rolling bearings with oil-air lubrication.
Inaugurated in 2003, the Coupled Pickling Line and Tandem Cold Mill (PLTCM) of ArcelorMittal Vega was designed with one tension reel. This arrangement required that after the production of each coil, the mill had to stop for cutting, evacuation and preparation to start a new coil. On that configuration the TCM remained stopped for about 52 seconds between each coil, with a production average time of 7 minutes per coil.
In 2010 the TCM was revamped with the introduction of the second tension reel, and from then on, the production of coils became continuous at the exit side, with no intervals between coils.
The revamping of the TCM followed the startup of the second hot dip galvanizing line (HDG#2), which was designed to target the white goods and construction markets. These segments have led to the introduction of thicknesses as low as 0.37 mm into the PLTCM product mix, which was originally designed to roll down to 0.40 mm but had little experience with strips below 0.50 mm. Figure 2 shows the

increase in production of materials with a thickness of less than 0.5 mm as of 2010.

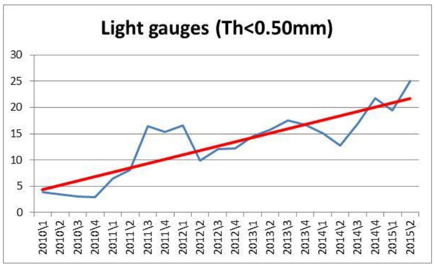

Figure 2. Percentage of the product mix composed of thickness<0.50mm.

With the increase in the production of low thickness material, there was an increase in the average speed of the TCM. The production of these materials doesn't reach the torque limits and the maximum speed can be reached. The originally designed maximum speed was 850 mpm in the exit of the mill. In order to increase the productivity this maximum speed was raised to 900 mpm in 2014.

This set of changes over time has brought the TCM to a new condition with different thermal cycle for the bearings, since they run at speeds greater than previously and without intervals. Yet, the specified bearing limits were not exceeded.

In 2014 during the disassembly of BUR bearings, marks were detected that indicated excessive temperature during rolling. Analysis of that event led to consider some consequences of excessive temperature in the bearings, such as change of lubricating oil viscosity, degradation of the sealing ring, and dilation of the internal components. From this event, some actions were defined to avoid new occurrences. One of these is the continuous cooling of the bearings through emulsion nozzles applied directly on the bearings. This action was applied in stands 3 and 4, where the bearings work at higher temperatures.

Another important action was the implementation of a periodic monitoring of the temperature of the bearings.

Using a portable temperature measurement device, the operator started to measure the temperature of all BUR bearings. The measurement was performed every three hours with the mill stopped for safety reasons and for correct operation of the measuring tool. Through this monitoring it was possible to follow the temperature of the bearings, detect some cases of elevation above the defined limit and take correction actions.

However, measuring every three hours does not guarantee the detection of events that may occur within this period, which keep the equipment at risk.

In addition, this practice has impacts on the equipment's availability and on the operator's working time. Each stop for temperature measurement lasts around 5 minutes, or 40 minutes per day. When possible, the measurement is performed during other stops of the equipment such as roll change. Thus, in the best of scenarios one additional minute could be considered for temperature measurement after the roll change every three hours, which would result in four hours of stops per month for bearing temperature measurement. Records show that the activity used to stop the TCM, on average, seven hours per month.

While this practice occurred, some solutions for online measurement of bearing temperature monitoring were proposed and evaluated. The aim was to install a system capable of detecting overheating in the BUR bearings without the intervention of the operator and without stopping the TCM.

This paper presents the solution chosen for the temperature monitoring of the BUR bearings of this mill. Information about the system development, installation and tests will be presented, as well as benefits and future works.

2 MATERIAL AND METHODS

After evaluating some solutions, it was decided to develop an in-house solution using wireless temperature sensors that were being developed by ArcelorMittal R&D Asturias. The following will show the system settings, their features and the installation steps.

2.1 Measuring hardware

The measuring system consists of sensors, repeaters and a base that receives the Zigbee signals and makes available through TCP communication. Overview of temperature measurement equipment can be seen in Figure 3.

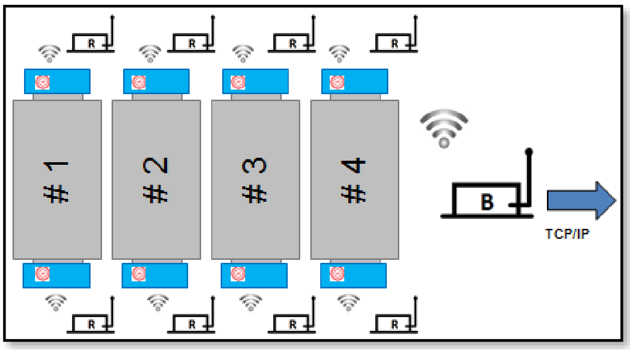

Figure 3. Measuring hardware overview

The sensor performs temperature measurement by thermistor integrated circuit and has measuring capacity in the range of 0 to 125 ° C. It is powered by 3 Vdc battery that allows operation for about one year and can be changed when necessary. The sensor used in this work can be observed in Figure 4.

Figure 4. Measuring sensor

The sensor encapsulation has been developed so that it can be installed inside the chock by machining or on the chock by mounting bracket. For this work a mounting bracket was made with dimensions suitable for installation on the outside of the bearing of the BUR. In each of the 32 existing bearings was installed one sensor, which was configured to indicate the number of the bearing in which it is installed. Example of sensors installed can be seen in Figure 5.

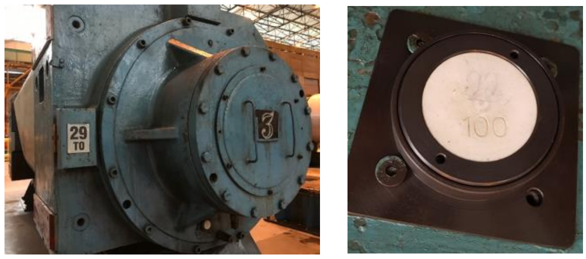

Figure 5. Sensor installed on chock

In order to amplify the signal from the sensors and ensure the arrival of the messages to the base, repeaters developed for the system are used. It uses transmission technology similar to the sensors, and is able to receive messages from the sensors and resend via Zigbee as higher intensity. They use antennas with longer range and 220 VAC power. In this work, eight repeaters were installed on the sides of the TCM to ensure communication of the sensors with the base.

The base is responsible for receiving the Zigbee messages sent by sensors or repeaters and transmitting this message through TCP communication to another system.

2.2 Control and supervision system

In order to integrate temperature measurement to the TCM control system, TCP/IP communication software was implemented in the main controller. From the messages received by the base, the information can be handled for decision making and forwarded to other monitoring systems and databases. Figure 6 shows the simplified architecture of this communication.

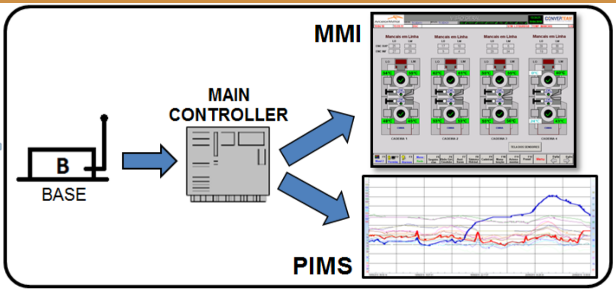

Figure 6. System overview

Information of the rolls in production is concentrated in the main controller and it is the best place to receive messages from temperature sensors. An algorithm was created to identify the messages and connect sensor information to the bearings that are in operation at the mill, which make easy diagnosis of events. The main information is sent to Human Machine Interface (HMI) used in the TCM operation. In the HMI some screens were changed in order to allow the operator to inform the identification of the bearings that come to work in each change of BUR. A new screen has been developed for real-time monitoring of the temperature of the rolling mill bearings. It can be seen in Figure 7, and provides information on the number that identifies each bearing as well as the current temperature measured by each sensor on that bearing.

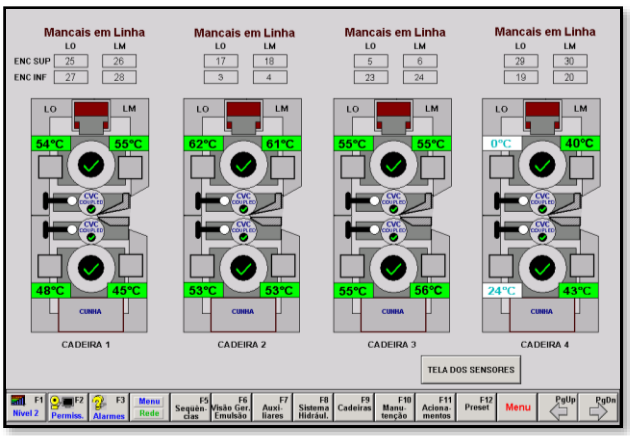

Figure 7. Bearing temperature screen

Using HMI tools, indications about bearing temperature and sensor conditions have been developed, that make diagnostics easy on the HMI. Through the screen animations, operator can easily identify whether a bearing is close to the maximum temperature, it is at normal temperature, or even if the bearing sensor is out of operation. Figure 8 shows some alert functions for the operator.

Figure 8. Alert Indication on HMI

As shown in Figure 9, a maintenance screen was also created where important information from all sensors and repeaters can be found. It is possible to check besides the temperature measured by each sensor, the battery level, signal strength, time of the last message sent and whether the sensor communication is directly to the Base or through some repeater.

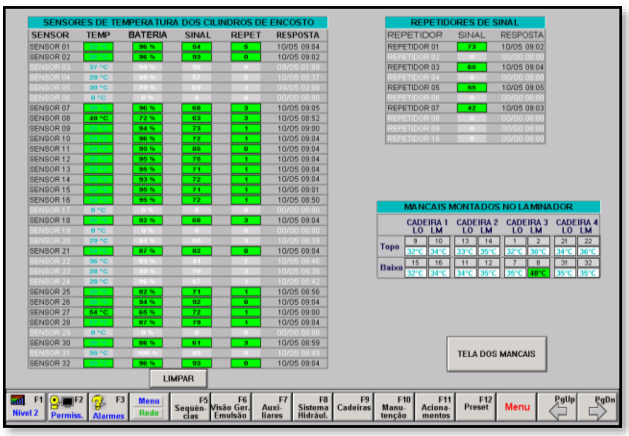

Figure 9. System maintenance screen

For database storage and long-term analyzes, Plant Information Management Systems (PIMS) was used. The main controller sends several production line information to this system and temperature monitoring system signals has been added. Through PIMS, analysis can be done through trend charts, custom screens

or other tools. The system can be accessed by office computers, with no impact on the production line.
For the temperature monitoring system, customized graphs were developed for temperature and battery analyzes which were important for evaluating the accuracy and reliability of the sensors during the test period and are still in use for system diagnosis with the advantage of relating the behavior with other rolling mill variables. Figure 10 shows an example graph for analysis of bearing temperature behavior and its relationship to process speed.

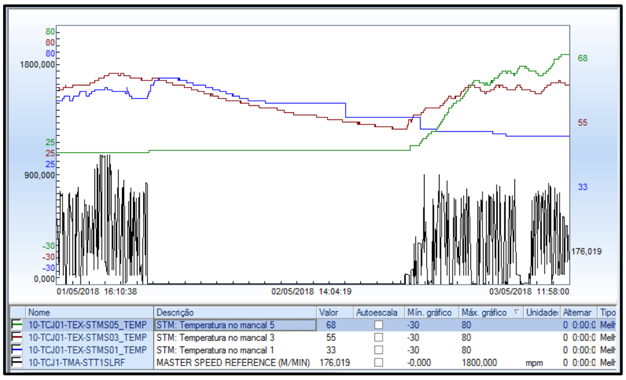

Figure 10. PIMS trend chart

Screens similar to the HMI were created in PIMS, which allow real-time animation or even with historical data in the database. Figure 11 shows an example screen created in PIMS for monitoring.

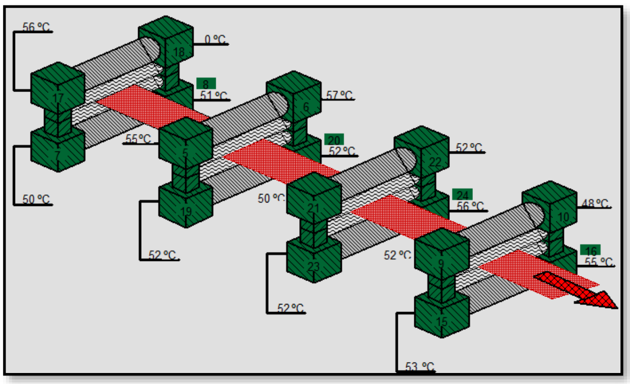

Figure 11. Screen with bearings temperature

An important feature of PIMS is the generation of e-mail alerts. Alerts were created for high temperature levels, connection failure with sensors and repeaters, as well as indication of low battery level suggesting replacement.
The measurement system hardware was purchased from ArcelorMittal's partner company for product development. The development of software for the acquisition, monitoring, control and supervision of the system was the responsibility of the ArcelorMittal Vega reliability team.

3 RESULTS AND DISCUSSION

Tests of this solution began in 2017, its consolidation and assembly were completed in 2018. Several tests were carried out until 2019, when the system was released for definitive operation.

3.1 Sensor accuracy tests

Accuracy tests have been performed for over a year to ensure that the sensor measurement is as accurate as possible. The reference for the test was the manual measurement performed by the operator through a portable infrared thermometer. During this period it was possible to identify the best position for mounting the sensor on the bearing surface and the necessary adjustments were made. Figure 12 shows the comparison between operator manual measurement and automatic system sensor measurement.

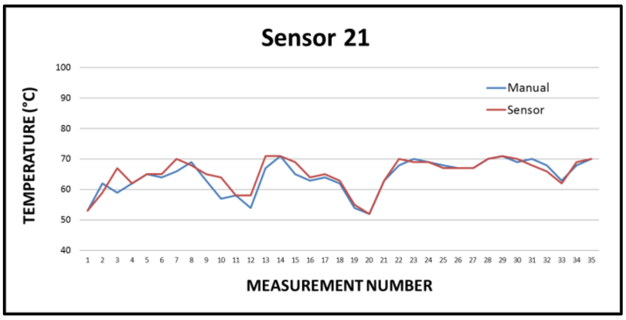

Figure 12. Manual x sensor measuring temperature

3.2 Battery life

Some sensors were installed in September 2017 and were used to evaluate battery life. The majority of the sensors reached a duration of more than 12 months, some coming to operate for 18 months as shown in Figure 13. By using the PIMS it was possible to monitor the evolution of the voltage drop of the batteries and set alarm levels for preventive exchange in order to avoid sensor failures during operation in the mill.

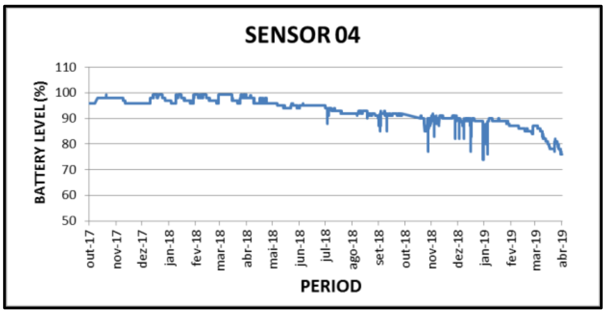

Figure 13. Battery life of sensor 4

3.3 Overheating detection

The events detected during the test period have proven the capacity of the system to identify these occurrences of overheating. Figure 14 indicates one example in which the sensor detected high bearing temperature between the manual measurements.

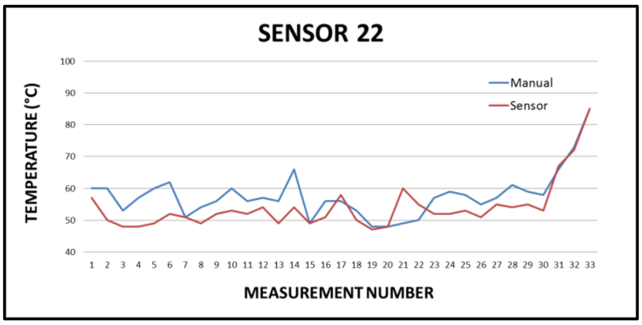

Figure 14. Overheating detection example

3.4 Main purposes

The main objective of the project was to increase the time available for the production line and for the operator which used to do manual measuring. The primary requirement was to ensure appropriate measurement and detection of overheating without compromising the integrity of the bearings.

The system was deployed gradually. First, the monitoring and alerting functions were enabled in parallel to the manual operator measurement. In the second step the frequency of manual measuring was reduced and the operator monitored the temperature by HMI in the interval between measurements. And finally the manual measurements are no longer made periodically and the system is in definitive use. The manual measuring tool is still available for the operator, who will perform the measurement in case of failure of any sensor.

Considering the initial condition, when an average of seven hours per month were used for this activity, the system brings great benefit by making these hours available for production, as well as freeing the operator for other activities. Considering that manual measurement will eventually be necessary due to failure of some sensor, a working rate of 90% of the system was considered, resulting in a gain of 6.3 hours of availability per month.

3.5 Additional features

In addition to the objectives achieved, it is possible to highlight additional gains, such as the follow-up of the life of the bearing in operation at the mill. Through the system it is possible to count the time each bearing is in operation and from this information to perform reliability, degradation and maintenance definition of each bearing.

Another important benefit is in safety. With the use of the system, it was possible to reduce the operator's time in areas with slippery floors or with potential equipment movement.

In terms of investment, the solution is low-cost due to the development of ArcelorMittal R&D Asturias hardware with Partner Company. In addition, the development and implementation of the control system were performed by ArcelorMittal Vega's internal team at no additional cost.

In progress are studies for application of the system in the temperature measurement of the work roll bearings and also for measuring vibration of the bearings.

4 CONCLUSION

This paper presented a temperature monitoring system that can detect overheating in the Backup roll bearings of a tandem cold mill. System features, deployment steps and tests were presented. The system was considered reliable, functional and replaced an activity that was in charge of the operators. The key benefits of the solution are the low deployment cost and gains with increased production line availability, and operator release for other activities, as well as improved predictive analytics quality.

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