The Digital Roll Shop for Improved Quality, Performance and Process Monitoring

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Summary
The challenges of a modern roll shop are becoming more demanding as the requirements for quality, productivity and automation are continually increased. Not only must the automated equipment be extremely accurate and reliable but it must also incorporate high levels of process control, process monitoring and product inspection. An integrated suite of software based functions has been developed by Pomini Tenova SpA, to achieve these required high levels of performance, monitoring and reporting in roll shop equipment. Such functions as Digital Texturing, on-line machine parameter monitoring, vibration monitoring, In-Process surface inspection and roll inspection combined in one device, continuous profile measurement and correction plus additional packages are available to operate as an integrated system. These functions provide an enhanced level of machine intelligence that delivers improved process monitoring and control.

Key Words
Roll shop, cold rolling, work roll, surface texture, roll inspection, crack and bruise, vibration monitoring.

Introduction
The requirements from a modern roll shop are becoming increasingly demanding with respect to both quality and productivity. In addition, there is a growing skills gap in the areas traditionally necessary to operate and maintain a high performance roll shop. This skills gap is being driven primarily by two effects; an aging workforce which is reaching retirement in record numbers and taking with them their skills and experience and the demand from manufacturing growth in some regions which has created a skills shortage. In either case, new employees have much different skill sets, with less emphasis on the traditional skills but with increased computer literacy. Turning toward automation is one strategic approach that has been identified for manufacturers to solve this skills shortage in the longer term. [1]
To meet these challenges Pomini Tenova has developed an integrated suite of automation and software based functions to take advantage of the availability of increasing computer power and data storage while at the same time making efficient use of the employee's available skills and productive time.
For the automated equipment to be extremely accurate and reliable it must also incorporate high levels of process control, process monitoring and product inspection. These functions are increasingly data driven, with sensors collecting and communicating large amounts of real-time information to the automation systems, operators, maintenance technicians and process engineers. The availability of this data provides performance analytics to optimize processes, identify problems and efficiently locate faults. It also allows employees to be productive when operating several items of equipment simultaneously. The combination of wireless technology, intranet, cloud services and the internet allow these software modules to share data and decisions to provide an enhanced the level of machine intelligence. As these systems become fully integrated a new level of machine learning is being developed in Tenova that will allow predictive analytics and dynamic process optimization.

Challenges of Modern Roll Shops
Modern roll shops are required to operate more efficiently with enhanced equipment productivity and utilization to allow greater output from fewer machines and significantly less employees. The quality demands and price competition of rolled products dictates that the roll shops must also supply consistent, high levels of quality to the rolling mill.
In recent years, roll consumption has become a higher priority in the overall consideration of roll shop performance. This has arisen with the introduction of more expensive, new technology rolls combined with reducing roll inventories.
To operate efficiently the roll shop must optimise both the scheduling of the equipment and the tracking of the rolls to meet the production demands of the rolling mill using real time communication and decision making.
Increasingly stringent safety regulations restrict the interaction between employees and the machines, in particularly moving equipment and suspended loads which are specific issues related to roll shops.

It is becoming increasingly difficult to find the required numbers of employees with the necessary skills or interest in roll shop operations: This can be due to a number of factors such as; the retirement of an aging workforce, new employees not attracted to learn these skills, greenfield locations and the rate of expansion in manufacturing in some regions.

Automation

The CNC automation of the roll shop core process: roll grinding, has been available for many years and the first automatically loaded CNC roll grinder was installed in 1986. Since that time the automated grinding cell has expanded to include multiple machines supplied by 3 axis CNC roll loaders (ARLS) located in a fenced automatic area [2]. Typically the automatic areas are arranged to maximize the employee's time by allowing them to supervise and monitor multiple machines from a centralised operating pulpit.

More recent installations have expanded this concept even further to include activities such as chock / de-chock and the roll movements in the roll shop outside automatic area. This expansion has been largely been realized due to availability of industrial WiFi which allows not only the communication between the machines but the co-ordinated real time scheduling of these machines and the tracking of individual rolls. Software such as the Roll Scheduling and Tracking System (RSTS) which is used in Ternium Pesqueria roll shop, shown in Figure 1, schedules and tracks all roll movements in the roll shop.

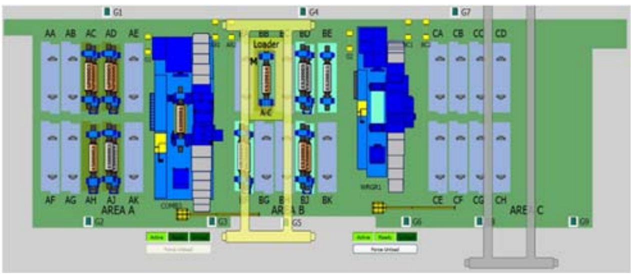

Figure 1: Ternium Pesqueria

The RSTS software was developed by Pomini Tenova and is able to exchange information with both the rolling mill and the customers ERP to define the upcoming rolling campaigns and determine future roll requirements. Once the mill production requirements are specified, the RSTS evaluates the availability of the rolls and selects the specific rolls to be ground and their optimum processing schedule. The schedule consists of the physical handling operations or "missions" that move the rolls through the process including any auxiliary operations that might be specified for each roll type such as cooling, inspection, de-chocking, etc. The scheduling is determined by the RSTS using predefined operating logic and priorities along with the current real time status of rolls and machines.

The system communicates this schedule of missions to the cranes and then is able to track the resulting roll movements and storage locations within the roll shop area. By monitoring the progress of the schedule in real-time the status (position, surface condition etc.) of every roll circulating in the roll shop is always available and displayed in an intuitive user interface. One of the advantages of RSTS is its ability to work with minimal external inputs once the operating logic and specific process flow of each roll type has been programmed. The newer installations will not only schedule, but also control, the operation of the OET cranes in the complete roll shop area.

This level of automation allows the operators to utalise their time for problem solving & efficient fault finding rather than the basic process tasks of roll grinding or loading rolls into the machines.

Increasingly the RSTS is being developed for decision making and supervision of all the other machines located the roll shop.

Within the automatic grinding area, once the loading of a specific roll into a roll grinder is recognised by the Grinder Data Interface (GDI) application, it sends all the rolls required details to the Grinder CNC. After completion of the grinding process the updated status and information is then sent to the RSTS. Data is also exchanged between the Roll Shop Management System (RSMS) and Automatic Roll Loading System (ARLS) which are interfaced for the necessary data exchange. When the RSMS and RSTS are both integrated, rolls and roll pairs are processed by RSTS according to their state in RSMS. For example, RSTS will recognize that a roll has been paired with another roll in RSMS, and RSMS will recognize that a roll pair has been created or un-paired in RSTS.

For the system to operate effectively it must efficiently allow operator interaction to override schedules, alter missions, input information and place machines or areas out of service.

As an example the RSTS has three operation modes as shown in Figure 2;

Auto Mode

- Operator defines a "Roll Priority List" indicating the priority associated to each roll to be ground; or
- Mill Operator defines a "Mill Schedule List" at mill level; or
- Mill Operator sets ranges of acceptable roll diameter.

Manual Data Input Mode

- Operator selects a list of missions by drag-and-drop actions on software GUI.

Direct Mode

- data input which forces the system to update based on the manual input of missions.

Similarly the ARLS can also have direct or manual input to override the automatic scheduling system using a drag and drop process to schedule missions.

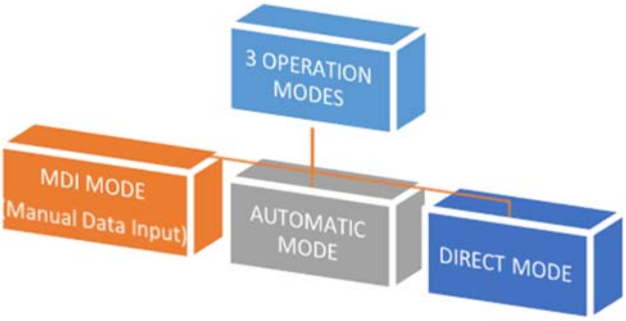

Figure 2: RSTS Operating Modes

When necessary operators can input data from the field via workstations or handheld RFID readers to identify rolls or change status. Handheld devices can also communicate missions and status to operators of the floor. Operators can safely access automated areas by placing the area out of service or if an access gates is opened.

Measurement and Process Control

Several systems are incorporated into the automation to measure aspects of the roll and use this information for process control and optimization. In particular: roll geometry measurement, crack and bruise detection and surface inspection are designed to achieve a crack and bruise free roll with correct geometry and surface condition with the minimal processing time and stock removal.

Roll geometry is measured by a high precision automatic caliper during the grinding cycle. With the Continuous Profile Compensation (CPC) activated these measurements allow the roll grinder to not only monitor, evaluate and correct main geometry parameters such as taper error and profile error but also to decide when the desired specification has been achieved and it is OK to proceed to the next grinding sequence. This minimizes the time & stock removal rather than using traditional methods of fixed parameters such as the number of grinding passes or quantity of material to be removed.

Inspection Systems

The latest generation of crack & bruise detection system uses a combination of three technologies, an increased number of sensors and a much higher sampling frequency to significantly increase the probability of detection for the various surface and sub-surface defects in the rolls. These defects typically originate from the manufacturing process or the extreme stresses that are developed during the rolling process. With the Pomini developed Inspektor^3 Eddy Current (EC) system it can scan 100% of the roll barrel during the grinding process and display the results as shown in Figure 3.

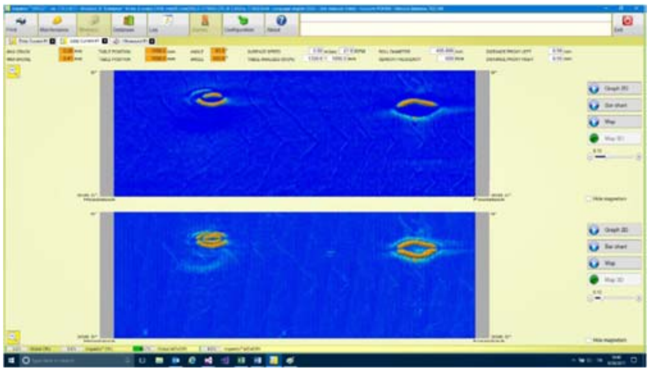

Figure 3: Eddy Current Display

The Eddy current system detects defects near the surface whereas the Ultrasound (UT) scanning with a 3000 Hz sampling rate and higher resolution than previous versions is able to reliably detect defects at much greater depths.

The relatively newly developed Creeping Wave technology is complementary to the eddy current and ultrasound. The ultrasonic longitudinal waves propagate just under the surface of the roll and are very sensitive to defects just below the surface, while insensitive to the actual surface condition of the roll. Although creeping waves are not useful to determine the size or the depth of the defect, the high sensitivity increases the probability of detection of the defect.

All three technologies can be combined into the compact, single Inspektor^3 unit shown in Figure 4.

Figure 4: Inspektor^3 with EC, UT and CW probes

The technology of these three systems is digital based, meaning they can be quickly and easily configured to suit different roll materials or to target specific defects and different depths as shown in Fig 5.

Because of the high sensitivity of the new eddy current sensors and the large amount of data collected, software is being developed to measure the surface quality and identify such typical surface defects as chatter and wheel marks.

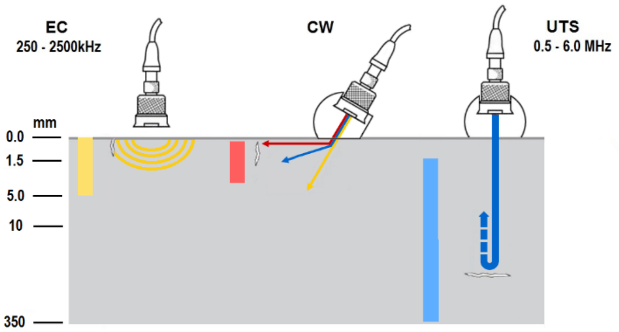

Figure 5: Depth range of EC, CW & UT sensors

This feature will allow the surface condition to measured during the grinding cycle and displayed for comparison with a pre-determined threshold to decide if to accept or reject the roll. The results of the inspection are stored in history to allow quality tracking and feedback after the rolls have been used in the rolling mill. A typical display is shown in figure 6

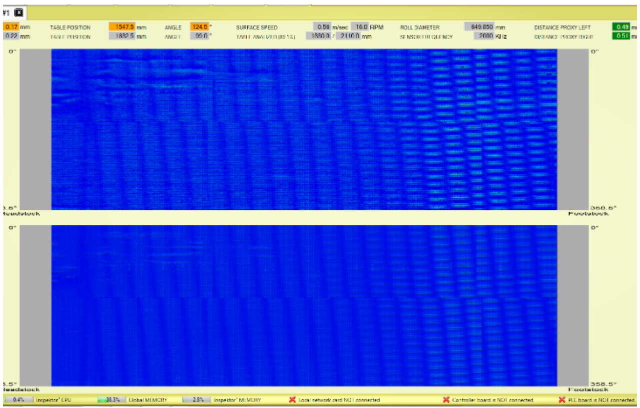
Figure 6: Surface Inspection Display

Machine Monitoring

Excessive vibration in certain frequency bands can adversely affect the finished roll surface quality. An additional module of the Inspektor[3] has the facility to measure the vibration present on the grinder and to alert the operator if these vibrations are exceeding the allowable thresholds. The system continuously acquires and processes the signals from up to 4 accelerometers placed in selected positions on the roll grinder. This data is analysed and the frequency spectra compared to known frequencies and thresholds for each machine. This can be used to indicate various machine or process conditions that could affect quality and notify the operator to take immediate corrective action. Typically issues such as worn bearings, machine resonance and regenerative chatter can be quickly identified during the grinding cycle. The display of this data and recorded history are very useful for diagnostics and detecting any change or deterioration in the machine or process.
A large number of additional machine and process parameters are monitored continuously on each machine. Such critical machine parameters such as such as motor current, oil temperature, machine status and alarms along with a full range of process parameters such as axis speed, spindle load, roll alignment and many more are monitored in real time.

Connected Machines

The data collected by the software systems can be transmitted via the internet for display, storage and analysis in a remote location using the 4.0 monitoring system.
This information can provide a live display of the machine condition and process performance using a number of dashboards for various aspects of the machine. A typical dashboard for a roll grinder machine is shown in figure 7.

Figure 7: Roll Grinder Monitoring remote dashboard.

The stored data is particularly useful to monitor the not just the current machine condition but the performance over a long time period to use for fault finding and process optimization. Currently this information is analysed separately, but future development is to provide integrated machine diagnostics and performance analytics leading to predictive maintenance and eventually machine learning capability to take full advantage of the data collected.

Pomini Digital Texturing™ System

This texturing process developed by Pomini Tenova relies extensively on software technology to generate the texture matrix and control the high frequency lasers that apply the texture to the roll surface. By using to software to control the fiber laser pulses each individual craters dimensions and placement can be controlled much more accurately than currently available texturing methods such as Electo-discharge texturing (EDT) and Shotblasting. This also enables the surface texture parameters to be independently controlled, in particular the Roughness (Ra), Peak Count (Rpc) and Skew (Rsk). Figure 8 shows the wide range of Ra vs Rpc that is produced by the process.
The main advantages of the system being software based is the flexibility to engineer the texture to suit the requirements of each particular application or customers product and to regularly upgrade the system. [3]

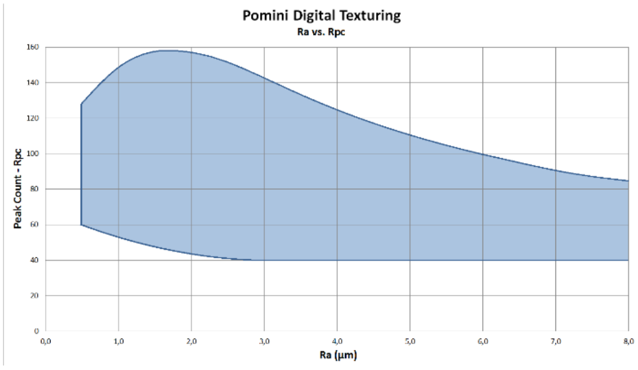

Figure 8: Ra vs Rpc

The Pomini Digital Texturing™ System can use a multiple number of texturing heads, depending on the productivity required to meet the requirements of a cold rolling complex.

Software Integration and Data storage

All the previously mentioned digital systems have been developed by Pomini Tenova as a suite of software and data storage that is fully integrated and networked to share information and status as shown in Figure 9.

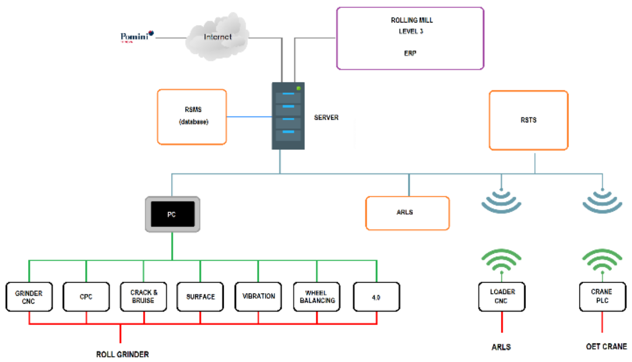

Figure 9: Software schematic

The availability of industrial WIFI has allowed the reliable communication with moving equipment such as overhead cranes to include the complete roll shop. Immediately the status of a roll or machine changes, such as the location of a roll, the condition of a roll from “used” to “ground” or a roll has new chocks installed, this information is immediately known by all the systems and updated on the various operator displays.

The Roll Shop Management System (RSMS) collects and stores a large amount of data to assist with the overall management of the roll shop. The RSMS is a server based software system for equipment such as:

- grinders
- rolls
- chocks
- chock bearings
- grinding wheels

The RSMS also communicates with the customer’s rolling mill to receive mill production data for correlation with the roll shop data and provide clear performance indicators useful to evaluate processes and suppliers.

Conclusions

Commencing from a simple PLC controlled Loader and CNC roll grinding machine in 1986 the continual development of automation and software has now reached the point where the entire roll shop area is automated. This progress has been made possible by taking advantage of the improved computing power, data storage and communication systems available in the digital era. The large amount of data collected and software developed now allows the automation to make real time decisions regarding scheduling and quality while and recording the actual events. This increased level of automation results in a minimal number of operators required to monitor a number of machines and maintain them at optimal productivity and quality performance. At the same time this also significantly reduces the expose of the operators to moving equipment and suspended loads.

Additionally the information collected about scheduling, process and machine operation currently allows analytics to be developed for predictive maintenance and process optimization. As these systems become fully integrated the next level of development involves the introduction of machine learning to further enhance the predictive analytics and eventually the dynamic process optimization

Abbreviations

ARLS – Automatic Roll Loading System
RSTS – Roll Shop Tracking System
PDT™ - Pomini Digital Texturing™
RSMS – Roll Shop Management System
RFID – Radio Frequency ID
Ra – Roughness Average
Rpc – Roughness Peak Count
Rsk – Roughness Skew

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