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INTEGRATED MEASUREMENT AND MANAGEMENT SYSTEMS FOR NEW AND UP-GRADED CNC ROLL GRINDERS IN STEEL AND ALUMINUM ROLLING MILLS[1]

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Abstract
By presenting the methodology and practical examples of roll grinders with integrated measurement systems such as laser, eddy current and ultrasonic, advantages regarding operation, production and safety through on-line detection of chatter marks, cracks, bruises and magnetism on the surface and within rolls are shown. The processing and intelligent use of the data are realized with a roll shop management system.
Key words: Roll grinder; Roll shop; Aluminum cold and foil mills; Hot mill; Cold mill; Plate mill.

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1 INTRODUCTION

In roll shops with roll grinders without integrated measurement systems, crack and bruise measurements of rolls are carried out off-line by a time consuming mainly manual process. Chatter marks are sometimes invisible and the affected rolls can leave “shadows” onto the rolled product. After the modernization of a grinder or at new state-of the art roll grinders such as a Monolith^{TM} or universal combination grinder, these measurements are an integral part of the grinding program. This paper describes the many improvements by such an automated process compared to conventional measurements. Special emphasis is given to the reliability of the production process and to the influence regarding the overall grinding time. Technical details of the measurements by laser, eddy current and ultrasound are discussed. Furthermore, a customized management tool for processing and using current and historical data in an intelligent way is presented.

2 STATE-OF-THE-ART ROLL GRINDERS IN MODERN ROLL SHOPS

In order to fully take advantage of advanced integrated measurement and management systems, it is required to have state of the art roll grinders in your roll shop. This applies for all kind of roll shops within cold, hot and plate steel rolling mills and within aluminum hot, cold and foil mills.

2. 1 Properties of Modern Roll Grinders

- Robust and proven mechanical design capable for running in a heavy industrial environment for decades 24 hours per day
- Trouble-free and low maintenance grinding wheel system, which is the heart of the machine, for chatter free grinding
- Integrated shape measurement system for a truly “grinding on the fly” function (measuring and grinding at the same time)
- Super-fast CNC hardware and special grinding software for optimum grinding results in terms of form accuracy, surface finish and grinding times in an automated mainly operator-free mode.
- With regard to hot and plate steel mills, a modern grinder is capable to grind the rolls with chocks-on or in-chocks respectively.

2.2 Monolith™ Grinder

In addition to the above mentioned functions it is important to mention that also a very important development regarding the foundation of grinders took place:
The Monolith™ grinder, a new generation of roll grinding machine, represents a quantum leap in technology. The design of the Monolith™ grinder isolates the machine from vibrations.
Originally the idea was to save the cost of intensive foundation works, with a huge concrete block. After grinding tests with the first built Monolith^{TM} Roll Grinder in 2001 it appeared that the performance is not only the same as with a conventional Roll Grinder but even better. Deeper investigations showed that not only the vibration coming from outside are much better dampened but also the vibration from the machine itself. The result is a much better performance with improved accuracies.

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The rough grinding of hot and cold mill work rolls, as well as, polish grinding of aluminum foil mill rolls and skin pass mill rolls has been successfully demonstrated.
The capability and efficiency of this revolutionary machine design has been proven under actual production conditions since 2003. Up to the beginning of 2010, in total 124 Monolith™ Roll Grinders have been delivered to mills all over the world; a big share of that to the aluminium industry. The Monolith™ Technology has been patented.
The polymer quartz material separates the cast iron top from the steel plate bottom. Due to the excellent damping properties of polymer quartz, vibrations created on the machine from the grinding process are deadened without exciting the machine structure.

2.3 Completely Modernized Roll Grinders

An interesting alternative to a new machine is sometimes the option to completely modernize an existing grinder. For a complete modernization mostly only the mechanical part of the machine such as bed, headstock, tailstock, grinding head and sometimes the steady rests are being reused after a thorough check, repair and up-grade. In most cases the entire electrical part will be new such as cabling, drives, motors and cabinets. The before described mechanical and electrical up-grade is the prerequisite for installing modern electronic equipment such as a CNC control and measurement system.

3 INTEGRATION OF ON LINE MEASUREMENT SYSTEMS

In many cases, even with such modern machines available, measurements of cracks, bruises and other surface faults of the rolls are being measured manually. In the following, the integration of these measurements into an automated grinding process are being described.

3.1 Laser Measurement of Rolls – the RSIS

To a high extent, the quality of the finished flat rolled product depends on the roll quality. In order to avoid possible quality defects, the rolls should be free from any surface defect.
Current standard steel strip inspection of flat rolled products use sophisticated camera systems. With this system quality defects can be detected, but not avoided. It makes sense to check the quality determining components prior to the rolling process additionally.
Besides that, more and more roll grinders are being run with no or minor operator interference as part of an automatic roll shop so that roll surface defects, if any, are not detected before running in a mill. Increasingly, roll shops are being run as Service Centers requiring a documentation of the delivered roll quality.
As response to the aforesaid said, Herkules has developed the process integrated optical roll surface inspection system (RSIS):
An optical sensor head (laser technology) is positioned in axial direction by an linear motor to the roll surface. The integrated distance control assures a constant distance between roll surface and optical sensor. This allows to cover all roll diameters and common roll shapes, like CVC or tapered shapes. In order to obtain repeatable measuring results, the roll surface is automatically cleaned by the means of

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compressed air. After the sensor head is positioned to the preset distance, the optical sensor is moved in longitudinal direction along the roll barrel. During this longitudinal movement the roll rotates and the roll surface is scanned in a spiral shape. The evaluation of the measured date is done on a separate industrial PC located in the control cabinet. Finally the measuring results are presented on roll grinder's CNC screen. In order to reduce auxiliary time, the optical surface scan can be done in parallel with the scan of the optional available crack detection system.
The following typical roll surface defects can be detected and classified:

- Chatter marks
- Feeds
- Spirals
- Scratch marks (commas)

The RSIS makes it possible to:

- check the roll surface prior to the flat rolled product,
- detect possible defects of ground roll surfaces and compares them with the stored data of typical defects,
- trigger warning signal to operator in case of conformity of detected defects with stored data,
- develop a classification databank of typical roll surface defects.

In a second step Herkules will develop a correction grinding software, to automatically modify the grinding process parameters according to RSIS results, e.g. prolog or repeat finish grinding, variation of grinding speed, etc.

Advantages:

- Automatically optical inspection of ground roll surfaces.
- Integration of RSIS within the automatic cycle of a roll grinder.
- Inspection protocol as quality documentation for the customer (rolling mill).
- Evaluation independent from operator and its skills.
- Even defects which are invisible for human eyes can be detected.
- Usage of well known and already proven sensor components.
- Fully automatic distance control (roll surface to RSIS sensor).
- Roll surface roughness does not influence the result.
- RSIS works independently from roll materials (forged steel, cast iron, …)
- Detecting sensitivity can be adjusted to customer needs.

Further Developments:

- Automatic correction grinding according to inspection results

Principle of Measurement:
A moving sensor head scans the roll surface in form of a spiral in z-direction while the roll is turning. Typically, that procedure takes place at the end of at the grinding process as a final inspection pass. However, the system is able also to monitor the surface in intermediate passes or even during the grinding process.
The first RSIS in Latin America will be installed a cold mill work roll grinder to be installed in the beginning o 2011 at the USIMINAS plant in Ipatinga, Minas Gerais Brazil.

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3.2 Integrated Eddy Current Measurements of Rolls

This type of measurement is the most traditional type of checking for cracks, bruises and magnetism on rolling mill rolls and is around for some decades.
The eddy current inspection system (EC tester) is used for checking the roll surface, detecting cracks and chill cracks up to a length of 3 mm, hardness increases and hardness variations as well as magnetic fields. In order to be able to detect these defects, they have to start at the roll surface.
The eddy current roll inspection can be carried out during the grinding process. The effective width of the eddy current inspection head is 40 mm and with several passes during the grinding process the complete surface of the roll is checked. This means that the total time of the roll in the machine is not prolonged due to the eddy check system. This is an important aspect when considering that modern roll shops are nowadays checking 100% of their rolls for cracks.
The surface defects are shown in a diagram which indicates the criticality of the cracks and hardness increases. Magnetic fields on the rolls are also indicated on the screen in order to avoid wrong decisions.
Surface defects are shown in an "unwound" representation of the roll shell by means of the radial and longitudinal coordinates of the roll. After the inspection the operator directly knows if the roll is free of defects or not. In case there is a defect, its size, surface structure and position on the roll are directly indicated.

System Components

- Sensor for eddy current scanning, Calibration kit and Portable installed Demagnetizer

The eddy check measurement is being applied by the steel industry (cold and hot rolling mills) and by the aluminum industry. With the regular control of the rolls and the development of their cracks and bruises during the life time, it is possible to guarantee that no spawling or other accidents will occur during the rolling process. An example where 100% of the work? rolls are being checked on line is ArcelorMittal Tubarão in Vitória, Brazil, where 4 roll grinding machines are equipped with eddy current measurement systems. This procedure is especially important for rolling mills where HSS rolls are being used: Since the introduction of these rolls and a 100% on line measurement no accidents in the hot strip mill of ArcelorMittal Tubarão due to spawling or other roll related issues have been reported. Since the inspection is realized during grinding, the overall grinding time for the hot strip work rolls is not affected by the eddy current measurements.
Within the aluminium industry the use of the eddy current system is becoming increasingly the norm in order to control the performance of the rolls. For example, for the new foil mill of CBA in Brazil the roll grinding machine is equipped with the on line measurement system. It is being used for detecting surface cracks and especially bruises in back – up rolls (at the ends of the barrel).

3.3 Ultrasonic roll sub-surface inspection

The ultrasonic roll inspection system (US tester) has been developed for the automatic sub-surface roll inspection.
The effective width of the ultrasonic inspection head is 10 mm. The measuring range of the standard sensor is 5 - 240 mm below the roll surface.

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The cooling water of the grinding machine will be used to conduct the ultrasonic signals in the inspection head to the roll surface.
The roll inspection with the ultrasonic system cannot be carried out during the grinding process and a clean surface (like after every grinding process) is absolutely required.
Sub-surface defects are indicated in mm depth, calculated on the run-time of the signal. The signal amplitude indicates the size of the defect in the roll interior.
Surface and sub-surface defects are shown in an "unwound" representation of the roll shell by means of the radial and longitudinal coordinates of the roll. After the inspection the operator directly knows if the roll is free of defects or not. In case there is a defect, its size, surface structure and position on the roll is directly indicated. Especially for the ultrasonic inspection the unwound representation of the roll shell is a very helpful and timesaving method to exactly localize the defect.

System components

- Electronic card for measuring integrated in the IPC, sensor for ultrasonic testing

4 ROLL SHOP MANAGEMENT SYSTEMS

In order to utilize in an intelligent way all the measurement data from your CNC roll grinder the next logical step is the installation of computerized roll shop management system.
There are different levels of functionality to suit with varying data collection and transmission according customer requests.

4.1 Receiving roll data

Information about roll geometry and surface finish build up the basis of the database of a roll shop management system.
In order to simplify the implementation of linking machines to a roll shop management system (RSMS) the Roll Data Collecting System was developed. This System bundles data from/to machine controls and communicates with the RSMS.
The Roll Data Collecting System (RDCS) receives roll data from the machine control during manufacturing and stores them in a database
Typically, the following data items are transferred from CNC to the Roll Data Collecting System:

- CNC Program name and curve number
- Operator ID
- Date and time of program start
- Roll diameter prior to and after grinding
- Roll profile prior to and after grinding Crown
- Roundness
- Eccentricity
- Shape deviation
- Out of center line
- Roughness and peak count
- Crack and bruise
- Date and time of program end

Before these data items are transferred to the Roll Data Collecting System they were buffered in the local Access database of CNC. After they are transferred to the Roll Data Collecting System the original copy in the CNC will be deleted.

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4.2 General Function Description

An Oracle database is installed on the Roll Data Collecting System to buffer roll data and machine information. All machining cycles of all rolls during the predefined time interval (for example: 3 months) are stored in the database. This part of the roll history is available on the system.
Roll data is stored in for the so called "**Production Cycle**". A production cycle represents the period of life time of the given roll. It consists of all process data that is gathered during a turn between mill and roll shop.

Operation Screens and Reports

Users access information from the database from the various operation screens (MMI Man-Machine-Interface) and reports. Users are categorized into 3 different access rights levels. Not all screen items are available for all users.
These screens and reports are developed using Oracle Forms & Reports Builder which can be displayed within a web browser such as Microsoft Internet Explorer.

Communication to machine

For each of the machines linked to the system a dedicated communication session runs in the background.
Communication between the CNC control and the Roll Data Collecting System is managed by an event trigger system located on the CNC control.
When a roll is loaded onto machine and operator has entered its roll ID, the CNC control informs the communication program which roll is loaded using a predefined trigger. Upon receiving this information, the communication program scans the database for corresponding roll machining schedule.
If a suitable schedule is found and a CNC program (including its curve ID) is specified inside the schedule, the program ID (and curve ID) will be sent to the CNC.
If no schedule of a target roll is found or if no CNC program is specified in the schedule, the system will select the program according to area code, line code, roll type, roll sub-type and mill production type from the machining program table.
Roll machining results are gathered during the process automatically. In case of a network malfunction, roll data are buffered in the CNC local database. As soon as the network is recovered, buffered data will be transferred to Roll Data Collecting System.

Communication to RSMS

TCP/IP stream sockets are utilized to communicate with external Roll Shop Management System.
After a roll is machined, operators can check its results using the MMI screen "Grinding Data" and eventually complete manual entry data (for example roughness values if the machine is not equipped with an automatic roughness measurement device). Use the "Send Data" button to trigger the data transmission to external Roll Shop Management System.

Operation Screens

Screens are used to access and manage information in the database.

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Register a roll by entering master data

For each roll to be handled by the system an account must be created in order to assign upcoming roll data accordingly. This is done by entering the master data of the roll in the database.

Roll process scheduling

For daily roll machining the Roll Data Collecting System offers a scheduling system to assist roll shop personnel in planning of grinder usage.

Machine plan of action

This screen gives the user an overview of the load of machine capacity according to roll schedules stored in the system currently. Since there are many influencing factors in the roll shop (like availability of overhead crane, crack in the roll etc.), this is only a rough overview of overall machine operation.

Starting a CNC program

After the grinding machine is loaded with a roll, there are two possibilities to start a grinding program:

Start a CNC program selected by an operator

In this case operator knows exactly which grinding program is to be used for grinding the roll loaded, he can select the target program from the menu list directly.

In addition to the program (and its related curve number) the operator needs to enter the following items at CNC operation panel prior to starting the grinding process: ● ID of the operator ● Roll ID

These items are necessary in order to assign the grinding results to the corresponding data records in the Oracle database.

Displaying & updating roll data of any manufacturing cycle

Use the “Grinding Data” screen to display data received from grinder. Three tabs are contained in this screen: “General data”, “Cross section” and “Roughness & Peak count”.

General grinding data
Cross section measurement
Roughness & Peak count
Roll profile and graphics of grinding results

In addition to discrete values of grinding results, the Roll Data Collecting System also stores graphic information of:

● Roll profile ● Cross section – Roundness, eccentricity etc. ● Crack & Bruise

5 ROLL WORKS

Roll Works is a software system for automation, quality assurance and optimization of grinding process for rolls in the steel, paper and printing industry.

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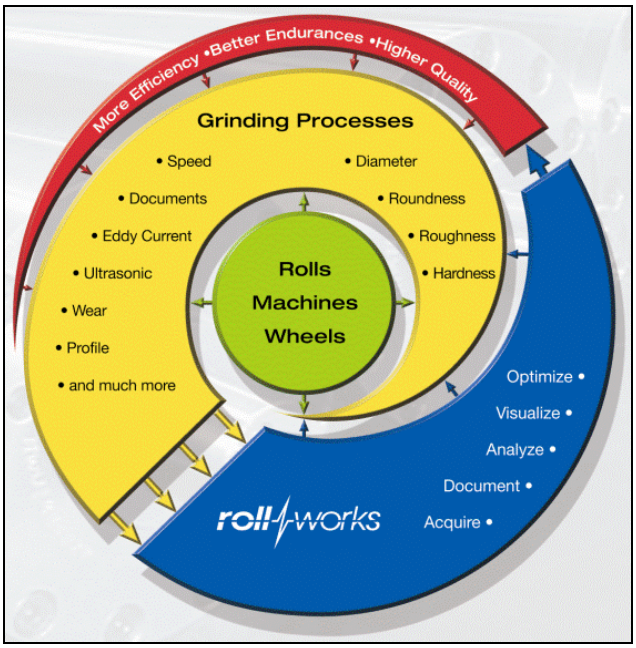
5.1 Modules

5.1.1 Basic

The basic function of *Roll Works* covers storing, visualization and the possibility of evaluation of essential parameters and measurements for the grinding process.



The data transfer is done using a permanent online interface to the grinding machines.
Visualization – online as well as offline – is done via the application *Roll Works Explorer*, which is the central interface between the system and the operator. Access to the data is generally done using a network interface – thus hardly any local restrictions in regard to principle possibilities for access exist.
The following data is acquired and stored:

Sequence of automatic programs, sequence of program steps.
Parameters for automatic programs, such as grinding program, operator, roll number.
Each last profile measurement to each program steps, in which such measurement is done.
Each Eddy Current, Ultra Sonic and concentricity measurement.
Used grinding parameters such as grinding pressure, cutting speed, roll rotation, etc.
Sequence of many other parameters, like profile deviation, stock removal rate, vibrations (only in connection with optional Vibration Monitoring System VMS)
Each error (alarm) occurred on the grinding machine.
The following statistical evaluations can be made:
Machine faults, machine availability
Grinding performance and roll production performance
Moreover, a document management system for administration of all common file types for rolls is part of the system.

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5.1.2 Process Control

With the module *Process Control* targets for grinding processes based on the process parameters and measurements known to the system can be configured. This module actively interferes in the sequence of the grinding machine and thus guarantees an automatic grinding under consideration of certain preset conditions.

Moreover, the system notifies freely selectable personnel groups (operator, foreman, maintenance personnel, etc.) for special incidents.

Individual rules can be determined for flexible definable roll groups (roll types, roll quality, stand, etc.).

For example rules for the following subjects are adjustable:

Minimum and maximum roll stock removal rates, where also the roll history (rolled tons, etc.) can be considered.

Eddy Current and Ultra Sonic threshold values.

Structure parameters for Eddy Current measuring values (increase display always on the same surface position yes/no, increased display of cracks and structure measuring values on identical surface position, etc.).

Diameter threshold values (under automatic consideration of actual counter roll diameter)

Profile threshold values (under consideration of optionally definable roll border)

Demand and execution of controlling measurements for checking of measuring devices

Output of warning message in case of implausible measuring results (diameter reduction in actually wear-free border area through roll use, etc.)

5.1.3 Optimizer (Automatic Optimization by Artificial Intelligence)

The optimizer automatically detects the most suitable grinding parameter under consideration of maximization of stock removal rate, minimization of dangerous vibrations (only in connection with optional Vibration Monitoring System VMS), minimization of grinding wheel wear and other influences under special consideration of each given conditions (roll diameter, wheel diameter, etc.).

Generally the *Optimizer* will make the grinding process deterministic, means controlled controllable. Only for illustration it is to be mentioned, that due to this a well-aimed reduction of target values is possible – for example a continuous load of machines can be stipulated, which of course will lead to different grinding performances due to variable demand.

Remark:

Roll Works Optimizer uses elements from the field of Artificial Intelligence; it is a learning machine with Fuzzy Logic elements.

Based on the grinding processes already completed, the system is automatically and continuously learning.

The achieved parameters will be transferred to the grinding machine automatically.

By using the optional Vibration Monitoring System VMS dangerous vibrations will be minimized.

Advantages:

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- Reduction of necessary men power, grinding times and wheel wear Improvement of roll surface quality and decrease of roll removal.

5.2 Network Requirements

Although ways of connection apart of TCP/IP are generally possible, the essential interfaces will be transacted over this.
For the connection of the grinding machine a fast network speed is required, at least 100MBit/s.
For the connection to our RSMS there are no such speed pre-conditions, here 128kBit/s (slow internet connection) would be sufficient.
Also for the connection of the instances of application *Roll Works Explorer* to the data bank resp. the software components of a.m. module a slow network connection is sufficient.
For remote access (Teleservice) via VPN the customer has to provide an Internet access.

5.3 Example Cost-Effectiveness Calculation

The below example shows possible advantages, which have been actually achieved by using the *Optimizers* at voestalpine in Linz in the area of work roll in hot rolling mill. 2006 is used as reference year as this was the last calendar year without use of the *Optimizer*.
Achieved improvements: 2008 vs. 2006
Reduction contact time 18,95%
Reduction grinding wheel wear 14,36%
Reduction consumption roll material 1,00%.

6 RESULTS

By incorporating the measurements of chatter marks, cracks, bruises and magnetism of rolls on-line into the roll grinder and using these data in a sophisticated management system, the roll shop operation gains more reliability. Furthermore, rolls remain less time in the roll shop and the life time of rolls can be enhanced.