Improved roll defect detection and logging

After 17 years of in-field development, Pomini Tenova has introduced a new generation of its roll ‘Inspektor’ which is able to detect smaller and deeper cracks at greater speeds. Use of simplified hardware and more user-friendly software operating on a PC in a Windows environment minimises maintenance needs and operator training.

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Pomini Tenova

Pomini Tenova sold its first-generation roll inspection system, Inspektor, in 1992. As customer requirements became more demanding, and experience using the system in the field grew with more than 350 units currently in operation worldwide, significant improvements in system architecture were implemented in 1995, 2000 and 2005. In 2008, Pomini Tenova presented a new generation of the system, the driving force being a significant improvement in defect detection and a decrease in complexity, and therefore training and maintenance needs.

Eddy current and ultrasound inspection are the proven methods of non-destructive testing for surface and sub-surface roll defects, respectively. Such technologies are used daily in most modern roll shops, however, requirements have become more demanding in terms of roll surface quality, the ability to detect smaller defects and greater repeatability and reliability, as well as reduced inspection times and improved guarantee of safety of the roll in service. This had resulted in increased complexity of inspection systems with higher costs for hardware, maintenance, training and spares. As a result, there is a now conflicting need to increase the performance of inspection systems while decreasing their complexity.

SYSTEM DESCRIPTION

All rolling mills suffer similar problems:

- Roll failures in the mill due to sub-surface roll defects cause significant loss in production and can create safety problems.
- Poor quality of strip due to surface roll defects causes significant loss as the product cannot be sold as prime or is returned to the supplier.

To address these issues the new Pomini Inspektor.net system was designed with two major objectives:

- To improve system performance by making sure smaller defects are detected with higher repeatability and reliability in less time and at more positions (ie, deeper inside the roll).
- To reduce the complexity of hardware, decrease the number of hardware boards and spare parts and the maintenance necessary, and to use off-the-shelf standard components wherever possible.

One major achievement in this latter objective is that there is no dedicated hardware inside the Inspektor.net PC to process data coming from the eddy current coils, ultrasound probes or accelerometers. All data reaches the PC through standard Ethernet; the only hardware necessary inside the PC is a standard Ethernet Network card (NIC) available off-the-shelf. Therefore, any PC can be used to drive the Inspektor.net system, including laptops, with no dedicated hardware boards. This simplifies installation, maintenance, spares and trouble shooting. Figure 1 provides an overview.

Since Ethernet is such a widely adopted networking standard, the technology will remain supported in the future and will not soon become obsolete. What is more, the network connection between the Inspektor PC and the Inspektor hardware can be modified to use fibre-optics and even wireless devices without incurring additional development cost.

The only dedicated hardware developed by Pomini is the eddy current head and a single hardware board common to each Inspektor.net feature. This translates to one board for eddy current inspection, a similar board for ultrasound inspection and a similar one for vibration and grinding wheel balancing. The input to these boards comes from the eddy current coils, ultrasound probes and accelerometers, respectively, and the output from each is a standard Ethernet cable to the Inspektor PC.

Inspektor.net is, therefore, a modular system, where any feature can be added independently from the others at any time, in any order, and without modifying the system already installed. The PC does not need to be changed either in hardware or software. To expand the system, only one board needs to be added for each feature, together with the relative coils, probes or accelerometers.

The fact that Inspektor.net only uses one board...
designed and built by Pomini for each module gives the following benefits:
- System maintenance is very easy.
- Spare parts kept in stock by the customer are reduced to a minimum.
- Operator training is easier and quicker.

These improvements already bring considerable value to any roll shop, but the main objective is to provide enhancements to the existing eddy current, ultrasound and vibration/wheel balancer performance. Improved inspection methods, increased repeatability and reliability of measurement, more sensors and an ability to detect smaller defects and at greater depths, have been achieved as well as reduced installation and set-up time and cost.

**INSPEKTOR.NET MODULE IMPROVEMENTS**

**Eddy current** The new eddy current head contains eight probes instead of the previous five, arranged differently so that there is no gap between the area scanned by one probe and that scanned by the next. The eight sensors each have a diameter of 2.5mm and, being located 0.5mm above the roll surface, can scan a contiguous strip 20mm wide, thus reducing scan time.

The new system measures absolute probe phase changes as well as amplitude changes, and this leads to improved differentiation between defect types. False reporting of distance variation as a roll crack is also reduced by up to 90%, and readings are independent of vibration in the mechanical support. Measuring the amplitude and phase relationships between relevant probe parameters yields a more accurate assessment of target properties (ie, position and defect). The phase relationship when only distance varies can be made orthogonal to the phase change associated with cracking, allowing easy separation of the two properties.

Different frequencies (250kHz to 2MHz) can be selected via software to improve defect detection in different roll materials. It is now also possible to operate at two frequencies simultaneously, if required, to eliminate the response from irrelevant signals.

A very small probe array head, measuring 60mm x 55mm, with two integrated distance proximity sensors, is used to reduce interference from chocks in order to scan 100% of the roll surface. The system can now measure surface cracks reaching a maximum depth of 5mm. Signal resolution is 2.5mm along the roll table length and 1.5° around the circumference of the roll. Circumferential cracks can now be clearly identified. All user adjustable components have been removed from the hardware, reducing installation and maintenance costs.

**Ultrasound** Two ultrasound sensors, instead of one, can now be used simultaneously, each focusing at a different
depth inside the roll, allowing the system to detect defects over a range of depths inside the roll (up to 350mm deep). The two sensors can also work at different frequencies (1–10MHz) to scan different roll materials with different scatter properties. The region inspected by each probe is individually adjustable and each probe can report defect amplitudes from up to four different depth ranges. Signal resolution is 10mm along the roll table length and 1.5° around the roll circumference for each sensor. The sensors are in contact with the roll via a film of water to provide ultrasonic coupling.

The pulse repetition frequency has been increased from 300 to 1,000 impulses/sec, thus increasing repeatability and reliability of measurements and improving the ability to find smaller defects. User-adjustable components have been removed from the hardware, reducing installation and maintenance costs.

Vibration and wheel balancing The number of accelerometers has also been increased from one to four and which can be used simultaneously on the grinder in different positions to monitor vibration in multiple locations, not just close to the grinding wheel, as shown in Figure 2. The software can switch automatically from one accelerometer to the next without user intervention, showing vibration from all four locations.

**Speed of scan** It is important to emphasise that with all of these improvements to the three modules, the new Pomini Inspektor.net can perform an eddy current scan, an ultrasound scan and check grinder vibration simultaneously.

**Tables 1** and **2** illustrate the cycle times for inspection of various roll diameters at two traverse speeds for ultrasound. At the slower traverse speed, ultrasound can detect cracks of a minimum 2.5mm while at the faster traverse the minimum is 5.0mm. The eddy current traverse speed was 20mm/rev in both cases and the minimum crack detected by this in the surface was 1.0mm.

**Presenting data** Since complex data comes from the eddy current and ultrasound sensors, it is important to record it and present it visually in a way that makes it easy for operators to understand what the condition of the roll

<table>
<thead>
<tr>
<th>Ultrasound (min)</th>
<th>Eddy current (min)</th>
<th>rpm</th>
<th>Roll diameter (mm)</th>
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<tbody>
<tr>
<td>10.6</td>
<td>5.3</td>
<td>16</td>
<td>1,450</td>
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<td>9.4</td>
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<td>2.6</td>
<td>1.3</td>
<td>66</td>
<td>350</td>
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Roll surface speed = 1.2m/sec  Roll table length = 1,700mm
Minimum EC measured defect = 1.0mm  EC traverse speed = 20mm/rev
Minimum UT measured defect = 2.5mm  UT traverse speed = 20mm/rev

**Table 1** Eddy current and ultrasound cycle times at 10mm/rev traverse speed for ultrasound and 20mm/rev for eddy current

<table>
<thead>
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</tbody>
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Roll surface speed = 1.2m/sec  Roll table length = 1,700mm
Minimum EC measured defect = 1.0mm  EC traverse speed = 20mm/rev
Minimum UT measured defect = 5mm  UT traverse speed = 20mm/rev

**Table 2** Eddy current and ultrasound cycle times at 20mm/rev traverse speed for US
is, and so decide if it can be sent to the mill without any impact on mill safety or product quality.

**EDDY CURRENT DISPLAY**

*Figure 3* shows a real-time EC scan with crack and bruise data, displaying the most important information needed by operators in order to decide what to do with the roll. The crack data is shown on the top plot and the bruise on the bottom.

The 2D display shows the following information:
- Cyan colour trace for cracks (top half of screen) and magenta for bruise (lower) indicate that a defect was found on the roll surface and the defect size is over the accepted threshold (horizontal green line), therefore the roll should be ground to avoid problems in the mill (damage to the roll, to the mill, or poor product quality).
- Red colour peaks indicate where a defect was found over the reject threshold (horizontal red line), therefore the roll could possibly be sent to the lathe because the defect is so large it would take too much time to grind out the defect.
- A green vertical bar indicates a region affected by magnetism. This can be a problem if a defect occurs inside this area because the reading of the eddy current sensor can be influenced by magnetism. In this case operators should perform an automatic degaussing cycle to remove the magnetic field and then perform another automatic eddy current scan.
At the top of the screen summary data is displayed as follows:

- **Value** Maximum crack/bruise value on roll surface.
- **Position** Where the maximum defect was found along the roll table length, with a resolution of 2.5mm.
- **Angle** Where the maximum defect was found along the circumferential direction, with a resolution of 1.5°.
- **Average** The entire data map is evaluated in real time and the average signal value is displayed, ignoring the 10% highest and 10% lowest values.
- **Delta** The difference between the maximum crack/bruise values and the average calculated, as described above.
- **Sensor frequency** The frequency for this scan.
- **Surface speed** Since the correct range for the roll surface speed is 0.5–3.0m/sec, it is important to know the actual surface speed to make sure the reading is reliable. If the surface speed is outside the correct range, a blue background colour indicates to the operator that something is wrong with the roll rpm set by the CNC.
- **Left/right** Position of the eight sensors is critical. They should all be 0.5mm away from the roll surface, so the two proximity sensors integrated inside the eddy current head, on both sides of the EC coils, are monitored every 500msec, and the distance reading is displayed in these fields. If they show that the head is not parallel to the roll surface, an alarm is generated, recorded and displayed to the operator.
- **Roll diameter** It is very important to know what the roll diameter was when the eddy current inspection was performed, especially when retrieving scan data from the database and comparing it to other scans for the same roll, so the diameter of the roll is indicated in this field. This information is also useful to build a knowledge base relating reduction of defects and stock removal for each combination of roll material, mill stand, roll type (back-up or work roll) and defect type (mechanical, fire, or circumferential cracks).

There are several ways to view eddy current scan results: in 2D, 3D or a map format. The eddy current map (see Figure 4) shows the surface of the roll as if it were laid flat with a data grid with each cell containing a defect value for each position on the roll surface, at a resolution of 2.5mm by 1.5°. Each cell contains a numeric value and a colour indicating a defect's severity. This gives an indication of the shape of the defective areas on the surface of the roll, for example, allowing operators to differentiate easily between thermal and mechanical cracks. Figure
Forming Processes

5 shows a 3D representation. Comparing this with the map, the operator can understand immediately that the defect on the roll surface is a thermal crack, which means taking a different approach for the grinding operation to remove the defect: less material ground means less money thrown away.

Figure 6 shows a real-time 2D ultrasound scan, displaying the information needed by operators to decide what to do with the roll. The top half of the screen shows the severity of the defect and the lower, the depth at which it occurs. The 2D ultrasound graphs give the following information:

- **Blue bars** indicate that the water flow used for coupling between the ultrasound sensor and roll surface in this region was not in the correct range. If the water flow is insufficient, the echo of impulses sent to the sensor from inside the roll body cannot be detected by the sensor. If the water flow is too high, turbulence will result, creating false readings.
- **Green bars** indicate that a defect was found to be above the accept threshold, therefore the roll should be removed from the grinder and not sent to the mill without further analysis, because it could explode creating significant damage.

At the top of the screen, summary data is displayed as follows:

- **Defect diameter** Maximum defect found inside the roll body.
- **Defect depth** Position inside the roll body, along the radius of the roll, where the defect was found.
- **Defect position** Where the maximum defect was found along the roll table length, with a resolution of 10mm.
- **Defect angle** Where the maximum defect was found along the circumferential direction, with a resolution of 1.5°.
- **Roll material** Material of the inspected roll.
- **Analogue gain** Gain used for driving the sensor, which automatically changes according to the different material of the roll.
- **Surface speed** Since the recommended range for the roll surface speed is 1–2m/sec, it is important to know the actual surface speed to make sure the reading is reliable. If the surface speed is outside the correct range, a CNC alarm is generated.
- **Calibration ON/OFF** This field indicates if the data is displayed after applying the dynamic calibration, which is used correctly to estimate the size of defects at different depths. If such calibration is not applied, defects closer to the surface appear to have greater severity since the echo is stronger.
- **Left/right** The position of the ultrasound probes is critical. They should be 0.5mm from the roll surface, so the two proximity sensors integrated inside the head are monitored every 500msec, and the distance reading is displayed in these fields. If they show that the head is not parallel to the roll surface, an alarm is generated, recorded and shown to the operator.
- **Roll diameter** It is very important to know what the roll diameter was when the ultrasound inspection was performed, especially when retrieving scan data from the database and comparing it to other scans for the same roll, so the diameter of the roll is indicated in this field. This information is also useful to build a knowledge base related to the roll life, taking into consideration the roll material, mill stand, roll type (back-up or work roll) and defect type (deep inside the roll body, close to the surface, across the shell-core interface, inside the core).
- **Sensor** Type of sensor used for the inspection affects all readings therefore it is very important to know which kind of sensor was used for this particular scan.
- **Coolant** Since the coupling between sensor and roll surface is one of the most important variables to be monitored to guarantee the correct functionality of the system, this flow value (l/min) is shown on the screen to indicate if the system is working correctly.

As with eddy current data, ultrasound data can be displayed in 2D, 3D and map format. The map shows...
the surface of the roll as if it were flat, in a data grid with a defect value for each position on the roll surface, with a resolution of 10 mm by 1.5°. Each ‘cell’ contains a numeric value indicating defect depth or defect severity, and a colour indicating defect depth visually. This gives an indication of the shape of the defect inside the roll, as shown in Figure 7.

One of the most important characteristics of any system running in a critical environment is its ability to diagnose itself, indicating clearly if there is a problem and what the possible solution is. The Inspektor.net software generates a lot of information during its operation, clearly identifying many possible anomalies and logging them in files that can be analysed at any time. Figure 8 shows a typical log of diagnostic information.

Maintenance In order to minimise maintenance, calibration, training required and spares inventory, the new Pomini system has the following features:
- Only one board designed and built by Pomini is necessary to run each module, everything inside the PC is a standard off-the-shelf component.
- No hardware adjustments are necessary to change the configuration on the Pomini boards as Pomini developed dedicated software that can be used to configure it.
- It is difficult to damage the boards because operators never need to touch them: there is no need to use oscilloscopes, voltmeters or to change any capacitors.
- The system has no drift with temperature and the components are very stable. A monthly calibration is all that is necessary to keep the system correctly tuned.
- Training for the Inspektor.net system is short because the software is user friendly and hardware is reduced to a minimum.
- Remote service is available so that Pomini personnel can connect directly to the customer system and check data in real time, reconfigure the system, perform a calibration or see diagnostic information.

Development environment The software is already compatible with Windows Vista and can also run under Windows XP with service pack 2. Written using Microsoft Visual Studio Team System 2008, it provides a standard Windows interface for use during inspection, maintenance and calibration. Some tools related to the Inspektor.net software have been developed using the latest programming language available on the market, namely Microsoft Visual C#.

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