POMINI INSPEKTOR.NET
EDDY CURRENT AND ULTRASOUND SYSTEM[1]

Giovanni Bavestrelli[2]
Andrea Tognoni[3]

Abstract

Eddy Current and Ultrasound inspection systems today are the proven methods of non destructive testing for surface and sub-surface roll defects respectively. Such technologies are used daily in modern roll shops, but as customer requirements become more demanding in terms roll surface quality, ability to detect smaller and deeper defects with higher repeatability and reliability, reduced scan times and increased safety, the applications became more and more complex. Pomini Tenova, with its strong experience coming from over 350 inspection systems supplied throughout the world, designed a new generation inspection system to meet the growing customer demands in system performance as well as to simplify the system design. The new system has an increased number of sensors, higher repeatability and reliability of measures, capability to detect smaller defects on the roll surface and inside the roll body, while at the same time having a smaller number of hardware boards than any other system on the market, and no dedicated hardware inside the controlling PC. This comes from the adoption of standard Ethernet technology, used not only to connect the Inspektor PC to the other machines on the network, but also to connect to the dedicated hardware inside the inspection system.
Key words: Roll inspection; Eddy current; Ultrasound; Vibration.

SISTEMA POMINI INSPEKTOR.NET DE EDDY CURRENT E ULTRA-SOM

Resumo

Sistemas de inspeção por Eddy Current e Ultra-som hoje são métodos comprovados de testes não destrutivos para detecção de defeitos superficiais e sub-superficiais em cilindros respectivamente. Tais tecnologias são usadas diariamente em oficinas de cilindros modernas, porém, como as solicitações dos clientes tornam-se mais exigentes em termos de qualidade de superfície de cilindro, capacidade para detectar defeitos pequenos e profundos com alta repetitibilidade e confiabilidade, reduzidos tempos de varredura e aumento da segurança, as aplicações tornam-se mais e mais complexas. Pomini Tenova, com sua vasta experiência de mais de 350 sistemas de inspeção fornecidos no mundo, projetou uma nova geração de sistema de inspeção para atender à crescente demanda dos clientes por performance e também para simplificar o projeto do sistema. O novo sistema tem um número maior de sensores, melhores repetitibilidade e confiabilidade de medições, capacidade para detectar defeitos menores na superfície e dentro do corpo do cilindro, enquanto ao mesmo tempo tem um número menor de componentes que qualquer outro sistema do mercado e não possui componente dedicado no PC de controle. Isto advém da adoção de tecnologia padrão Ethernet usadas não somente para conectar o PC do Inspektor a outras maquinas na rede, mas também para conectar com o componente dedicado dentro do sistema de inspeção.
Palavras-chave: Inspeção de cilindros; Eddy Current; Ultra-som; Vibração.

1 *Technical Contribution to the 45th Rolling Seminar – Processes, Rolled and Coated Products, October 21st to 24th 2008, Ipojuca - Porto de Gainhas - PE*
2 *Software Engineering Director, Pomini Tenova, Castellanza (Va), Italy*
3 *Inspektor Product Manager, Pomini Tenova, Castellanza (Va), Italy*

1 INTRODUCTION

Eddy Current and Ultrasound inspection systems 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, but as customer requirements become more and more demanding in terms roll surface quality, ability to detect smaller defects with higher repeatability and reliability, reduced scan times and increased safety, the applications become more and more complex. Increased complexity usually comes with higher costs for hardware, maintenance, training and spares. There are apparently conflicting needs to increase the performance of inspection systems while at the same time decreasing their complexity.

Pomini Tenova sold its first generation roll inspection system, Inspektor, in 1992. As customer requests became more demanding, while at the same time experience on using the system in the field grew with over 300 units currently in operation worldwide, significant improvements in system architecture were developed in 1995, 2000 and 2005. In 2008, Pomini Tenova is presenting its new generation system, the biggest leap forward since the introduction of the first Inspektor in 1992. The driving goal behind this new project was a significant improvement on system performance in defect detection while at the same time decreasing system complexity, and therefore training, maintenance and spares.

2 INSPEKTOR.NET

All rolling mills suffer similar problems:

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

To reduce these problems to a minimum, Eddy Current and Ultrasound systems are used daily in most roll shops to inspect rolls before sending them to the mill. As mill requirements become more demanding, together with roll shop performance needs, inspection systems become more complex. As a result, most roll shops experience the following issues:

- Increased complexity in inspection system hardware.
- Higher maintenance costs due to the higher complexity.
- More skilled operators required to maintain the inspection systems.
- More training required to keep operators up to date with new technologies, hardware changes, software updates, etc.
- Many different hardware boards are customized by inspection system suppliers to increase Eddy Current and Ultrasound device performance, and this leads to higher costs for the systems.
- Many spare parts must be kept in stock to avoid long down time for inspection systems in case of hardware problems.

To address these issues commonly found in roll shops, the new Pomini Inspektor.NET system was designed keeping in mind two major objectives:

1) Improve system performance by making sure smaller defects are detected with higher repeatability and reliability in less time and in more positions (like deeper inside the roll).

2) Reduce hardware complexity, decrease the number of hardware boards, the number of spare parts and the necessary maintenance, and also 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 eddy current coils, ultrasound probes or accelerometers. All data arrives to the PC though a standard Ethernet network; 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, even laptops, with no dedicated hardware boards. This simplifies installation, maintenance, spares and trouble shooting.

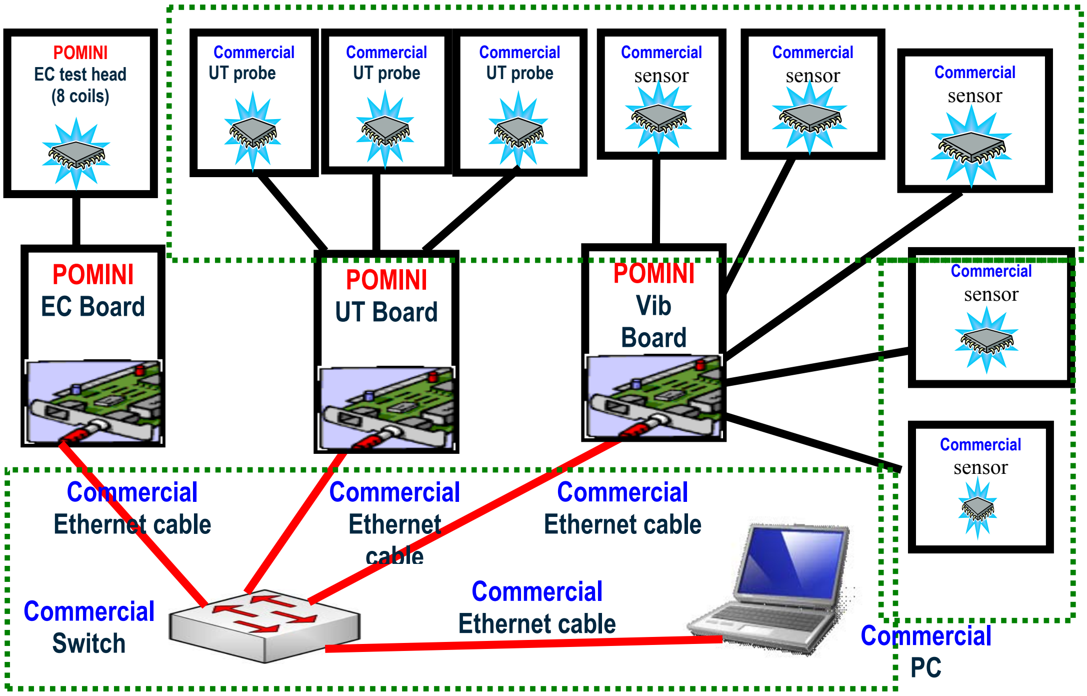

Figure 1: Inspektor.NET system overview

The layout shown in Figure 1 highlights the simplicity of the Pomini Inspektor.NET hardware architecture: everything shown inside the green rectangles is available as standard off-the-shelf devices (PC, Ethernet cables, switch/router, Ultrasound and Vibration/Wheel Balancer sensors) at a very low cost from a large number of suppliers.

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

Other than the standard components, outside of the green rectangles in Figure 1 the diagram shows the only hardware developed by Pomini: the eddy current test head and one separate independent hardware board for each separate and independent Inspektor.NET feature. This translates to one board for eddy current inspection, one board for ultrasound inspection, and one board for vibration and wheel balancing. The input to these boards comes from eddy current coils, ultrasound probes and accelerometers, respectively, whereas these boards' output is a standard Ethernet cable to the Inspektor PC.

The Inspektor.NET is therefore a modular system, where any feature can be added independently from the others at any time and without modifying the system already

installed. Customers could purchase an Ultrasound Inspektor.NET system without Eddy Current capability, and add Eddy Current functionality at a later stage. The reverse is also possible, as is any combination of the three features (Eddy Current, Ultrasound, and Vibration/Wheel Balancing). Note that the PC does not need to be changed, in hardware or in software, to expand the system; only one board must be added for each feature, together with the relative coils, probes or accelerometers.
The fact that the Inspektor.NET only uses one board designed and built by Pomini for each module (Eddy Current, Ultrasound, Vibration/Wheel Balancer) causes the following customer benefits:

1. System maintenance is very easy
2. Spare parts to be kept in stock at customer site are reduced to a minimum
3. Operator training is easier and quicker

These improvements already bring considerable value to any roll shop, but the first important objective of the Pomini Inspektor.NET system is to provide enhancements to the existing Eddy Current, Ultrasound and Vibration/Wheel Balancer performance, improving inspection methods, increasing repeatability and reliability of measures, adding more sensors, detecting both smaller and deeper defects, and also reducing installation and set-up time and cost.
Significant changes have been made to improve system performance in the new Inspektor.NET. For example: the number of eddy current coils has been increased from five to eight, to reduce scan time; the number of ultrasound probes has been increased from one to three, to increase the system's ability to find defect close to the surface and deeper inside the roll body; the number of accelerometers has been increased from one to four, so that the system can monitor grinder vibrations in different places at the same time.
What follows is a brief summary of the improvements in system performance for the three Inspektor.NET modules.

Eddy Current system highlights:

- The new eddy current test 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 the area scanned by the next. The eight sensors with a diameter of 2.5 mm (0.098") can scan a contiguous strip 20mm (0.787") 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 different defect types. False reporting of distance variation as cracking is also reduced by up to 90%, and this makes readings independent from vibration in the mechanical support. Measuring the amplitude and phase relationships between relevant probe parameters yields a more accurate assessment of target properties (i.e. distance 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 (250 KHz to 2 MHz) can be selected via software to improve defect detection in different roll materials. It is now also possible to operate at two different frequencies simultaneously, if required, to eliminate the response from irrelevant signals.
- A very small probe array head, 60 mm x 55 mm in size (2.362" x 2.165"), with two integrated distance proximity sensors is used to reduce mechanical interference with chocks and be able to scan 100% of the roll surface.

- The system can now measure surface cracks reaching a maximum depth of 5 mm (0.197”)
- Signal resolution is 2.5 mm (0.0984”) along the roll table length and 1.5° along the circumference of the roll.
- Circumferential cracks can now be clearly identified.
- User adjustable components have been removed from the hardware, reducing installation and maintenance costs.

Ultrasound system highlights:

- Three ultrasound sensors, instead of a single one, can now be used simultaneously, each one focusing at a different depth inside the roll, allowing the system to detect defects closer to the roll surface and deeper inside the roll (up to 350 mm deep, or 13.78”). The three sensors can also work with different frequencies (1 MHz to 10 MHz) to scan different roll materials with different scatter properties.
- Pulse repetition frequency has been increased from 300 to 1000 impulses per second, thus increasing repeatability and reliability of measures and improving the ability to find smaller defects.
- 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 10 mm along the roll table length and 1.5° along the circumference of the roll, for each sensor.
- User adjustable components have been removed from the hardware, reducing installation and maintenance costs.

Vibration and Wheel Balancing

- Four separate accelerometers can now be used simultaneously on the grinder in different positions to be able to monitor vibration in multiple locations, not only 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.

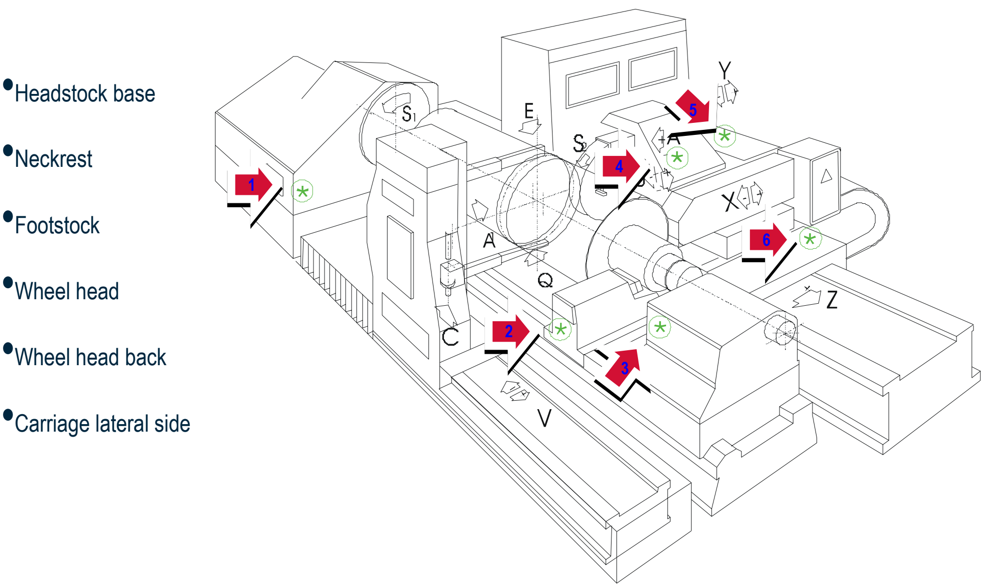

Figure 2: Possible accelerometer positions on the grinder

It is important to emphasize that with all these improvements to the Eddy Current, Ultrasound and Vibration/Wheel Balancing modules, together with the new hardware architecture which uses a commercial PC and commercial Ethernet cables, switch/routers and TCP/IP protocols for handling data from all sensors involved, the new Pomini Inspekor.NET system can perform an Eddy current scan, an Ultrasound scan, and check grinder vibration all at the same time.

3 EDDY CURRENT AND ULTRASOUND CYCLE TIME

EC surface speed = 1.5 m/sec
EC traverse speed = 20 mm/rev
Minimum EC measured defect = 1.0 mm
UT surface speed = 1 m/sec
UT traverse speed = 10 mm/rev
Minimum UT measured defect = 2.5 mm
Roll table length = 1700 mm

UT CYCLE TIME (min)	EC CYCLE TIME (min)	ROLL DIAMETER
13.1	4.3	1450
11.3	3.9	1300
8.5	3.0	1000
7.7	2.7	900
7.1	2.4	800
6.1	1.9	650
4.5	1.5	500
3.0	1.1	350

EC surface speed = 1.5 m/sec
EC traverse speed = 32 mm/rev
Minimum EC measured defect = 2.5 mm
UT Surface Speed = 1 m/sec
UT traverse speed = 20 mm/rev
Minimum UT measured defect = 5 mm
Roll table length = 1700 mm

UT CYCLE TIME (min)	EC CYCLE TIME (min)	ROLL DIAMETER
6.5	2.7	1450
6.1	2.4	1300
4.3	1.9	1000
3.9	1.7	900
3.5	1.5	800
2.8	1.2	650
2.1	0.9	500
1.5	0.7	350

4 EDDY CURRENT AND ULTRASOUND SOFTWARE

Since complex data comes form the Eddy Current and Ultrasound sensors, it is very 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 is, and decide if it can be sent to the mill without impacts on mill safety or product quality.
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.

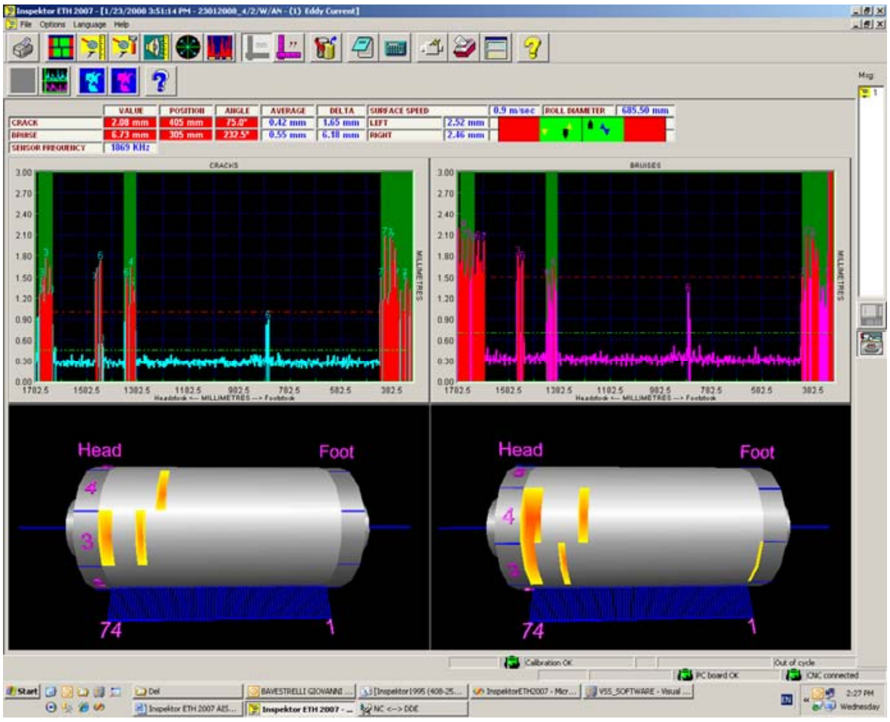

Figure 3: Real time crack and bruise scan data, 2D and 3D

The 2D graphs show the following information:

- Cyan colour for cracks and magenta colour for bruise indicate that a defect was found on the roll surface and such defect is over the accept threshold (dotted 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 indicates that a defect was found over the reject threshold (dotted horizontal red line), therefore the roll could possibly be sent to the laithe because the defect is so big it could take too much time to grind the roll.
- Green colour background indicates a region affected by magnetism. This can be a problem if a defect was found inside the same area (like shown above), 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 another automatic Eddy Current scan to ensure the roll surface will not show the same problem.

At the top of the graphs, some summary data is displayed:

- *Value*: maximum crack/bruise value found on the roll surface
- *Position*: position where the maximum defect was found along the roll table length, with a resolution of 2.5 mm (0.0984”)
- *Angle*: 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 values and the 10% lowest values
- *Delta*: this is the difference between the maximum crack/bruise values and the average calculated as described above
- *Sensor frequency*: it is the sensor frequency selected for this scan
- *Surface speed*: since the correct range for the roll surface speed is from 0.5 m/sec to 3.0 m/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*: the position of the eight sensors is critical, they should all be 0.5 mm away from the roll surface, so the two proximity sensors integrated inside the Eddy Current test head, on both sides of the EC coils, are monitored every 500 msec, and the distance reading is displayed in these fields. If they show that the test 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 defect reduction and stock removal for each combination of roll material, mill stand, roll type (BUR or WR) and defect type (mechanical crack, fire crack, circumferential crack).

There are many different ways to see eddy current scan results, in 2D, 3D or map format. The eddy current 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 2.5mm by 1.5°. Each "cell" contains a numeric value and a colour indicating its severity. This gives an indication of the shape of the defect areas on the surface of the roll, for example allowing operators to differentiate easily between thermal and mechanical cracks, as shown in Figure 4.

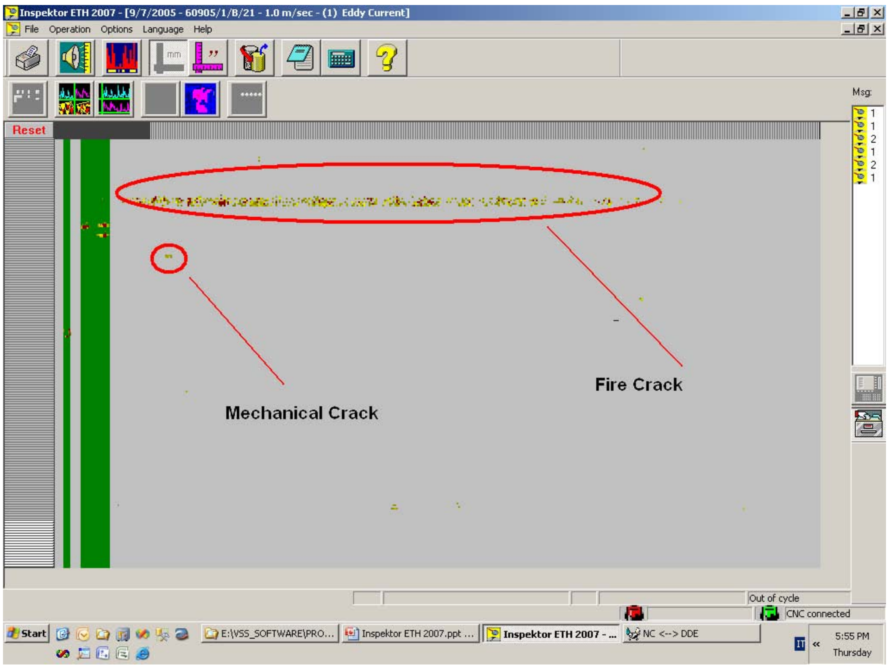

Figure 4: Real time crack scan map

Figure 5 shows a real time ultrasound scan, displaying important information needed by operators in order to decide what to do with the roll.

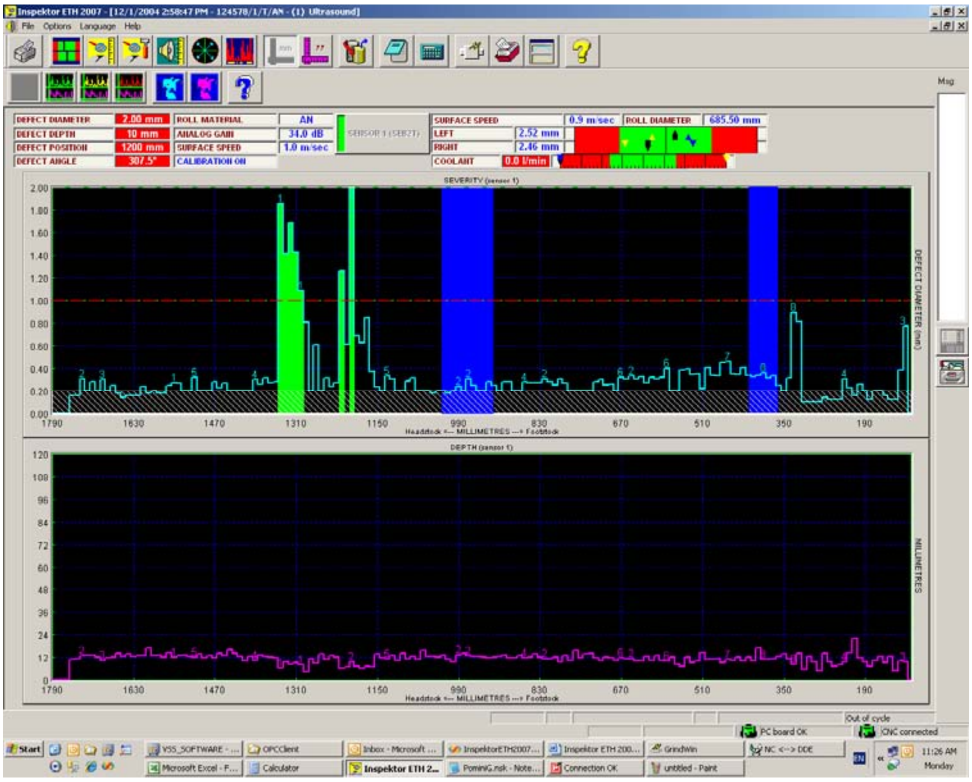

Figure 5: Real time Ultrasound scan data, 2D

The 2D graphs show the following information:

- Blue background colour indicates that water flow used for coupling between Ultrasound sensor and roll surface is not in the proper range. If water flow is insufficient, the echo of impulses sent from the sensor inside the roll body will not be detected by the sensor itself. If the water flow is too high, turbulence will result, creating false readings.
- Green colour indicates 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 graphs, some summary data is displayed:

- *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*: position where the maximum defect was found along the roll table length, with a resolution of 10 mm (0.393”).
- *Defect angle*: angle where the maximum defect was found along the circumferential direction, with a resolution of 1.5°
- *Roll material*: the material of the inspected roll.
- *Analog gain*: the 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 from 1 m/sec to 2 m/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 to correctly estimate the size of defects at different depths. If such calibration is not applied, defects closer to the surface appear as having a bigger severity since the echo is stronger.
- *Left/Right*: the position of the ultrasound probes is critical, they should be 0.5 mm from the roll surface, so the two proximity sensors integrated inside the test head are monitored every 500 msec, and the distance reading is displayed in these fields. If they show that the test 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, keeping into consideration the roll material, mill stand, roll type (BUR or WR) and defect type (deep inside the roll body, close to the surface, across the shell-core interface, inside the core).
- *Sensor*: the 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 the most important variables to be monitored in order to guarantee the correct functionality of the system, this 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 6.

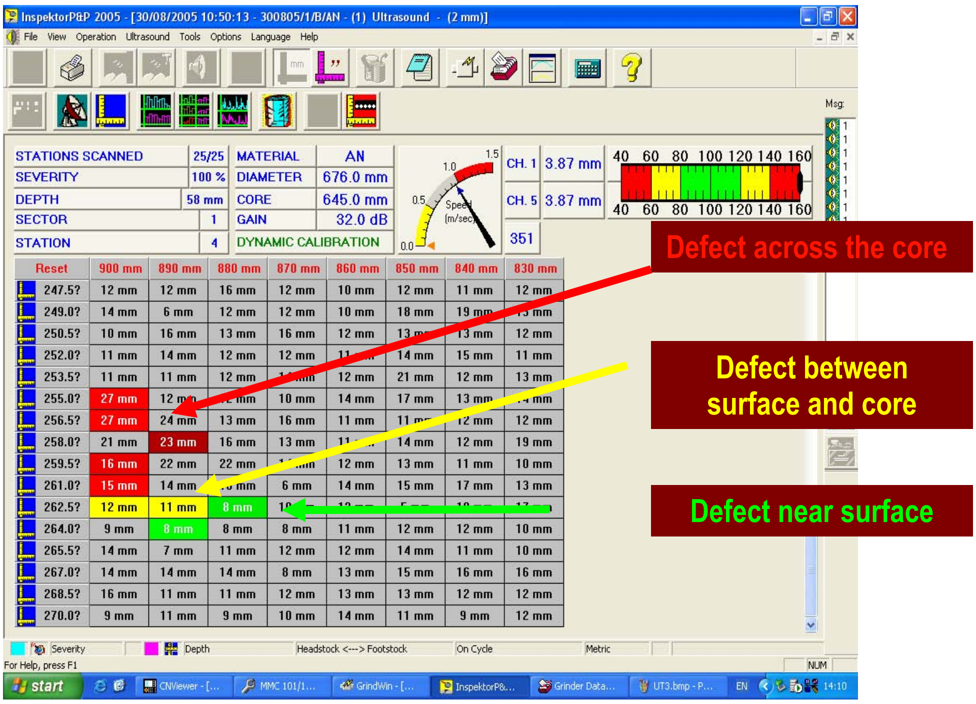

Figure 6: Ultrasound map

5 DIAGNOSTIC SOFTWARE

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 its 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 analyzed at any time.

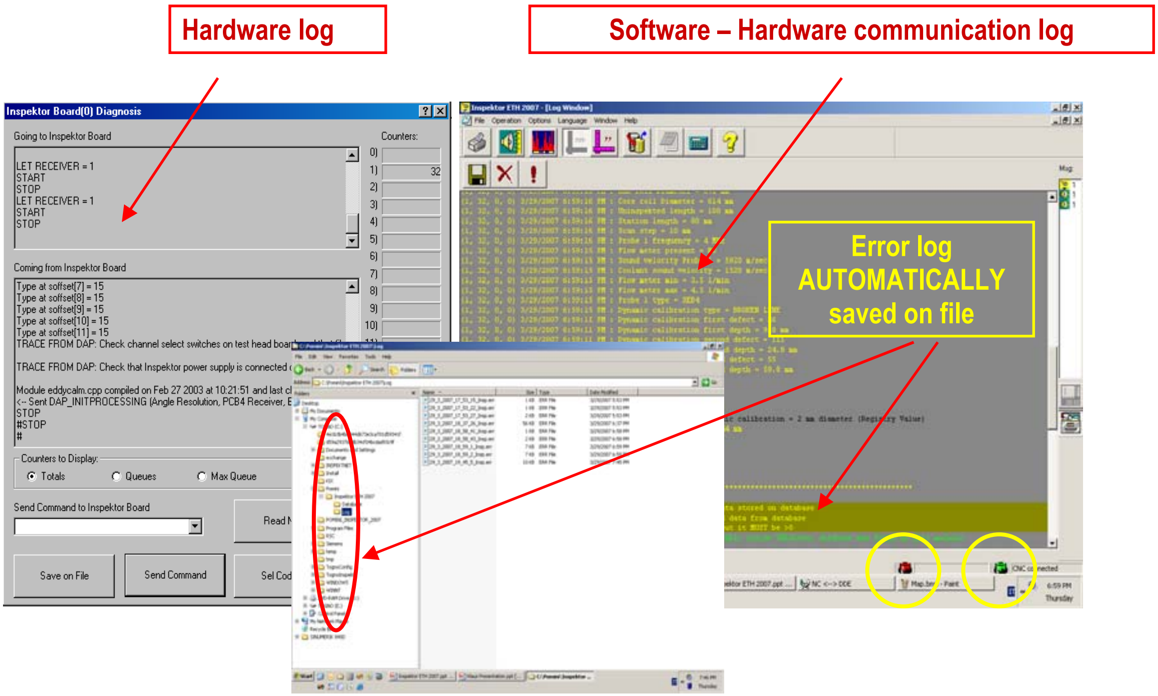

Figure 7: Logging diagnostic information

6 MAINTENANCE

When discussing inspection systems with prospects, some questions arise frequently from the discussion:

- How difficult is to maintain the system?
- How often do I have to calibrate it?
- How many days of training do I need for my operators to be sure they can maintain the system by themselves?
- How many different spare parts do I have to keep in stock to be sure to reduce the down time period if I have a failure in the inspection system?
- How easy is it to contact the supplier if I can’t fix the problem or if I have a question regarding the interpretation of the results?

These questions motivated the design of the new Pomini Inspektor.NET system.

- Only 1 board designed and built by Pomini is necessary in order 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, Pomini developed a dedicated software that is included with the Inspektor.NET system and that can be used to configure every aspect of 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 limited because software is user friendly and hardware is reduced to a minimum.
- For the same reason, the number of spare parts to be kept in stock on customer site is also limited.
- 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.

Figure 8: New Eddy Current test head

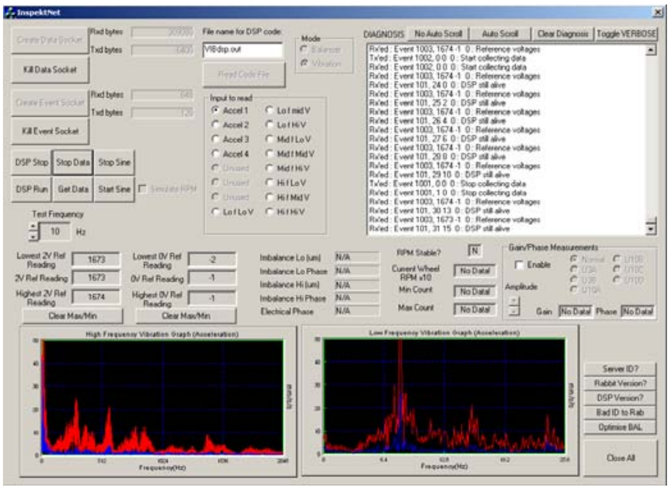

Figure 9: Hardware monitoring software

7 DEVELOPMENT ENVIRONMENT

The Inspektor.NET software is already compatible with Windows Vista and, of course, can run under Windows XP 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#.

Acknowledgements

A special thanks to Trevor Bray, Peak Design and Developments Pty Ltd and all the people in Pomini Tenova who worked with dedication to make this new system a reality.

REFERENCES

1 A. Tognoni, “Digital roll inspection technology becomes Plug & Play”, Steel Times International, Vol 30 Jan/Feb 2006, pag 30