The Next Generation of Mill Roll Inspection Systems
a Case Study of Whemco Steel Castings: New Rollmate Inspection System

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INTRODUCTION

In the fall of 2002, Innerspec introduced and patented an Ultrasonic Testing (UT) inspection system for surface inspection of mill rolls. This novel approach was designed to overcome known limitations of Eddy Current (EC) systems such as:

- False readings due to residual magnetism in the roll.
- Variability due to roll material chemistry.
- Bad readings due to lift-off variations.
- Very limited sensitivity to fire cracks and other shallow surface defects.
- No sensitivity to sub-surface defects.

This first full UT system from Innerspec (Rollmate G1) had only three ultrasonic channels and limited inspection capabilities, but the UT technique was proven very effective, and several mills adopted it with great success. Following Innerspec's lead, other manufacturers started offering some UT inspection for internal and surface inspection on their high-end systems, but the industry as a whole still relies heavily on EC systems for flaw detection in mill rolls. An important unintended consequence of this reliance is that many users will not try new rolls -or even change suppliers- for fear of destabilizing a fragile inspection process that is known to be finicky, and requires careful calibration for different materials and inspection conditions.

Fig.1. Rollmate G1

In 2014, Whemco Steel Castings Inc., a leader in mill roll manufacturing and service, approached Innerspec Technologies to expand the original Rollmate design with more capabilities. The objectives stated by Whemco for this new design were:

- It should consistently detect <u>all</u> defects that could be present in a roll, surface and internal, whether they happen during manufacture or during operation.
- It should be able to inspect rolls of any chemistry, forged and cast, and provide consistent and reliable results in a mill environment.
- It should be designed to be used by mill personnel without special knowledge and training in non-destructive testing.

TECHNIQUE AND EQUIPMENT

After discussions with Whemco and several rolling mill operators, the defects of interest were divided in five categories:

- Surface defects on the first 2mm of the surface of the roll that appeared during hot and cold rolling. As the roll hardens, these cracks can be generated in any orientation and be as shallow as 0.1mm in depth and 1-2mm in length.
- Near-surface defects from 2-60mm that could include cracking and internal porosity created during the manufacturing process.
- Core-shell disbond and laminations on cast rolls. In addition to detection of these defects, there was also an interest in measuring the thickness of the shell to estimate its remaining life.
- Internal defects from 60mm to the center of the roll that have been created during the manufacturing process, and can eventually propagate to the surface and cause spalls.
- Soft-spots or “bruises” caused by annealing of the surface during mill rolling. On EC systems these defects are detected at the same time as the surface cracks.

After evaluation and testing on different specimens with artificial and natural defects, it was decided that the new system will have to grow from 3 to 20 inspection channels and include the following tests:

- Surface inspection in all four orientations (axial clockwise and counterclockwise, and circumferential left and right).
- Near-surface inspection in all four orientations.
- Normal inspection (0º) with near and deep focus. This normal beam channel would also be used for measurement of the core shell.
- EC/electromagnetic sensors for bruise detection. Instead of using EC sensors for both crack and bruise detection, the electromagnetic sensors on Rollmate G3 would be designed and tuned specifically for detection of bruises. They should be very easy to calibrate, and tolerate much greater variability in chemistry and magnetism without triggering false positives.

On the final system all the channels were duplicated to provide a complete inspection swath of approximately 25mm per pass to provide fast inspection speeds.

For the user interface, we conducted several interviews with mill operators and decided to adopt all the views that they liked from existing systems, plus some new features not available on any commercial equipment. The final system includes the following:

- Four different views.
    - Oscilloscope (A-Scan in UT). The X axis shows time and Y amplitude. It permits looking at individual defects or features and analyze the defect response. Typically used during calibration, for defect analysis, and for troubleshooting the equipment.
    - “Spread out roll” map (C-Scan in UT) in which the X axis shows the axial dimension of the roll, Y the circumference, and the defects are represented with changing colors (user configurable).
    - Bar graph. The X axis shows the axial dimension of the roll and Y the maximum amplitude of any defect around the circumference at a particular axial point.
    - 3D view. Full representation of the roll that permits turning, rotating, and selecting cross sections to visualize the defects within the roll.
- Ability to turn on and off different tests. All the tests (surface, sub-surface, deep, bruise) are color coded and can be visualized individually or as a group.
- Reporting.
    - Full reports exportable to PDF for every inspection.
    - Roll history to track previous test results for each roll as it returns to the roll shop for service.

- Web-browser interface. For this application, Innerspec introduced NDT-Web™, the first user interface in the Non-destructive Testing industry that provides full access to the equipment in real time through a web browser. This technology includes some unique capabilities:
    - The system broadcasts its own wireless signal for simple access from any device (tablet, phone) using a regular browser and IP address (no client software needed). Alternatively, users can connect to the equipment using an external video monitor or Ethernet port.
    - Permits easy customization of user controls and display without affecting the operation of the equipment.
    - Includes built-in features to connect to NDT-Link™, Innerspec's web portal for support, spares purchasing, and automated/remote operation and process control tools.

With regards to the hardware, the main challenge was to integrate all 20 inspection channels in a compact package that could fit on different grinder models. After several iterations, the final configuration includes:

- Modular design with four different components; instrumentation, inspection head, actuator, and PLC and couplant management. These modules can be re-arranged to fit the customer's requirements and the grinder model.

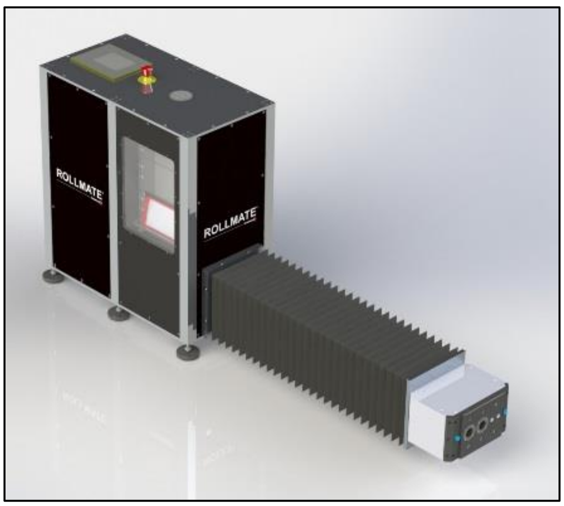

Fig. 14. Free-Standing on Grinder Platform

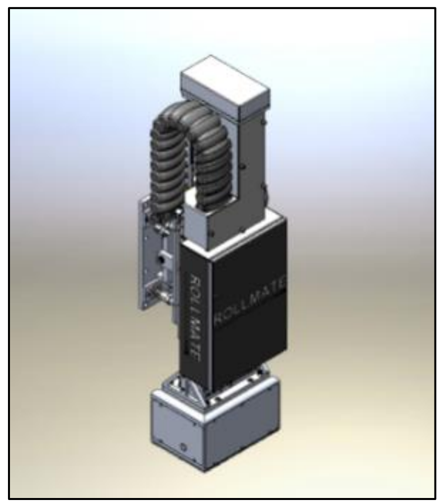

Fig. 15. Overhead Mounting

- Maintenance-free sensor head. Innerspec used a proprietary water column design that keeps the sensors protected and clean, and reduces couplant consumption by 90% when compared to conventional models. The head also includes six proximity sensors that keep the inspection head assembly in the proper position throughout the scan, and protect against potential crashes with adjacent equipment. When the automated scan sequence begins, the system deploys the sensor assembly and will rapidly retract it if anything comes near its path.

RESULTS

Lab Tests

Preliminary tests for this new NDT design were completed on a partial roll sample provided to Innerspec by Whemco and other calibration specimens. This roll sample had a number of natural and machined defects.

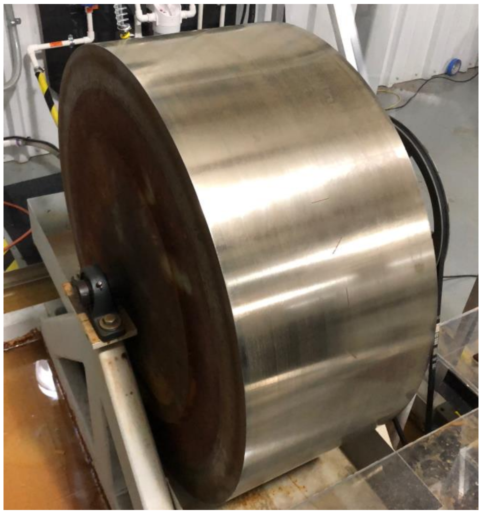

Fig. 2. Whemco Roll Sample

Defect	Type	Location	Size
Fire cracks	Natural	Surface & Subsurface	Various patches
Side Drilled hole	Machined	Below surface - 60mm	1.5mm DIA
Core-Shell Disbond	Natural	Roll core	Various patches
Notch – Longitudinal	Machined (EDM)	Surface	0.3mm deep x 25mm long
Notch – Circumferential	Machined (EDM)	Surface	0.3mm deep x 25mm long
Notch – Oblique	Machined (EDM)	Surface	0.3mm deep x 25mm long

Fig 3. Roll Sample Defect Table

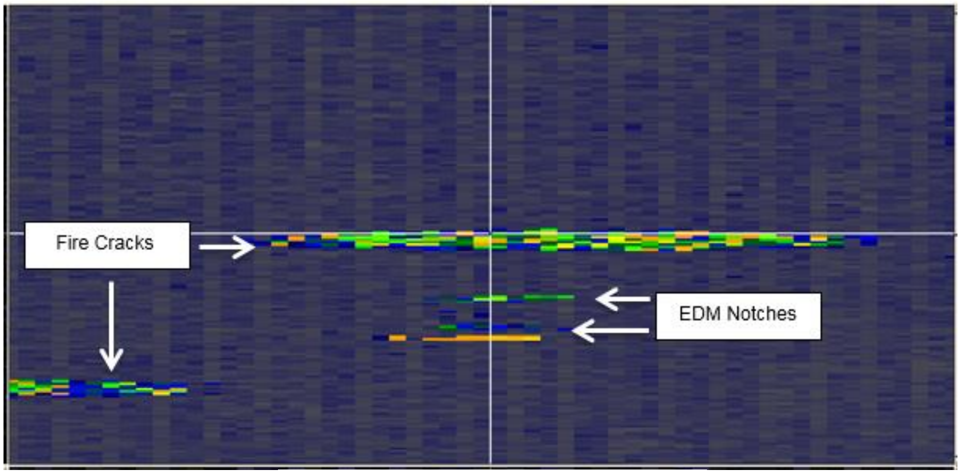

Fig. 4. Roll Sample Surface Scan

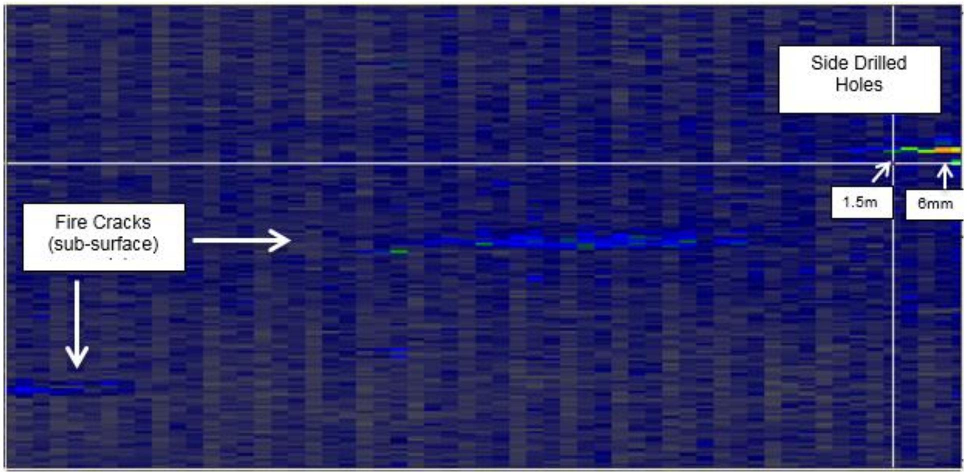

Fig. 5. Roll Sample Sub-Surface Scan

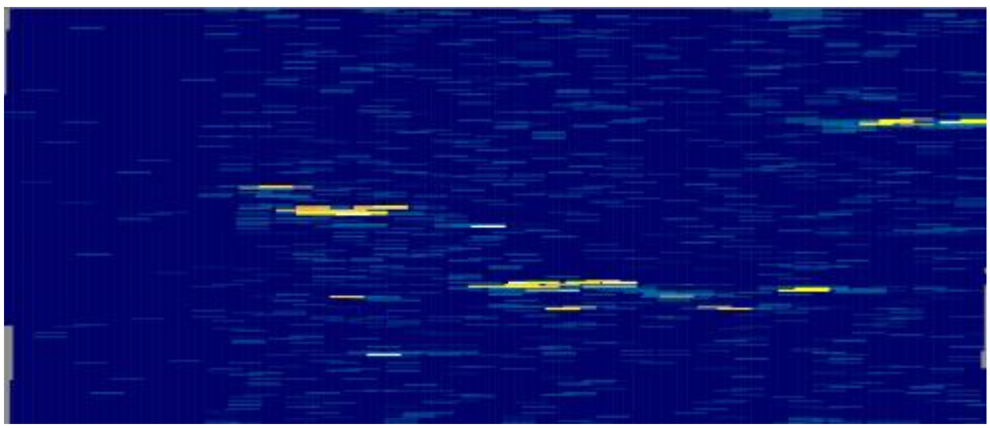

Fig. 6. Roll Sample Core-Shell Disbond Scan

On-Site Tests

Over the course of several months, Innerspec and Whemco engineers tested and optimized the technique and equipment inspecting rolls that had been used in different mills. Some of these rolls included defects that could not be detected using conventional EC inspection systems and other unusual problems.

As an example, the following results were obtained on an Indefinite Chilled Double Poured (ICDP) work roll with a hardened shell of 45mm nominal thickness which had been particularly hard to test with EC systems. On the left side there is a small area with fire cracks which also exhibited the traits of a bruise because of the surface hardness change. On the bottom right, there is a small crack which resulted in a fatigue band at approximately 20mm depth.

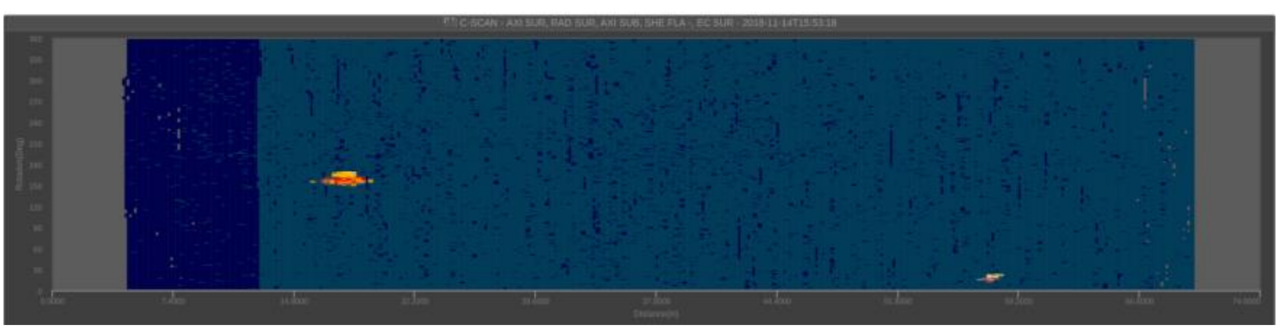

Fig. 7. Whemco Test – Surface & Sub-Surface

The image below shows both defects in the 3D view.

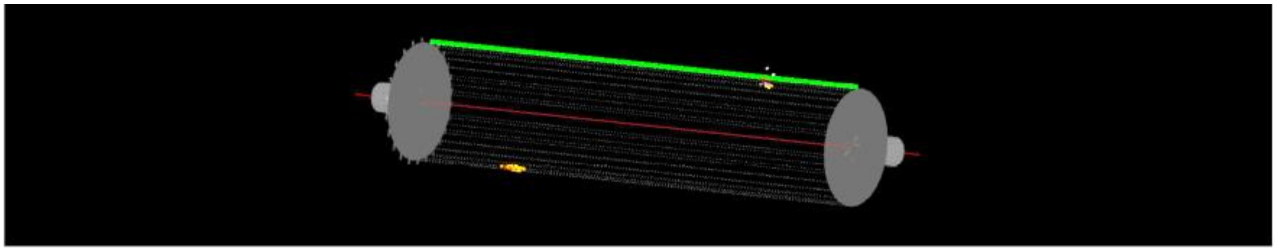

Fig. 8. Whemco Test – 3D View

The image below from the same roll represent the defects in a bar chart. The maximum amplitude is shown for each scan rotation, and an alarm threshold is represented by the dashed line. The first image shows the fire cracks on the left, and the small fatigue band crack on the right. This image displays data from the channel for axial oriented defects.

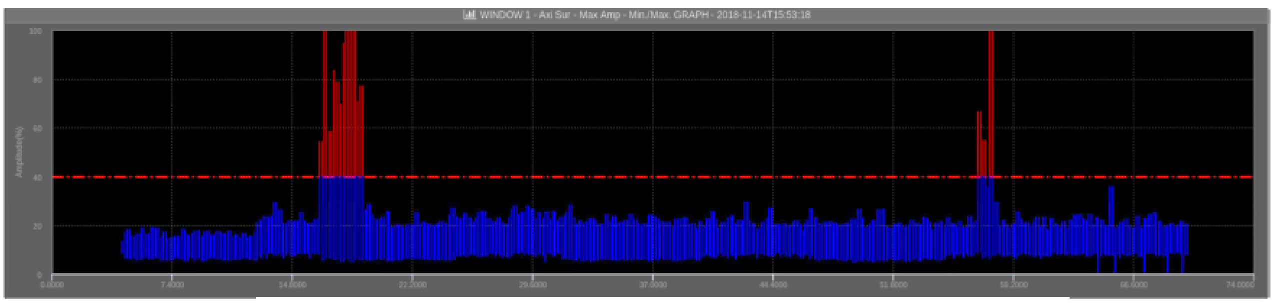

Fig. 9. Whemco Test – Maximum Amplitude Chart, Axial Defects

This second image from the same scan displays the data from the channels used for circumferential defects. While the cracks on the left are detectable, the small crack on the right is completely undetectable by this channel due to the orientation of the defect. This crack was missed by a new Eddy Current system installed at the customer.

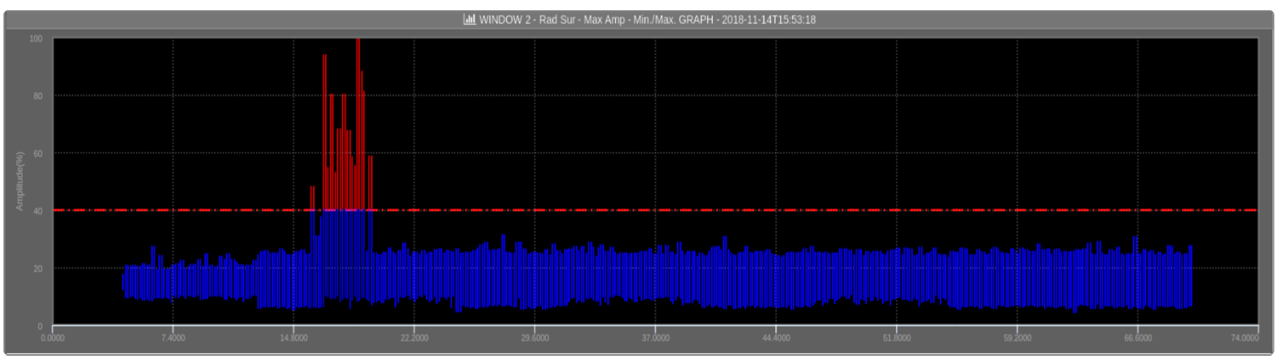

Fig. 10. Whemco Test – Maximum Amplitude Chart, Radial Defects

The importance of having sensors scanning in all four directions for detection of surface and near-surface defects became more obvious over time since the amplitude of the reflections from natural defects will vary greatly depending on the orientation of the sensor and the geometry of the defect.

An example of this phenomenon is shown on the two scans below. A fairly large defect is clearly visible on the axial channel inspecting counterclockwise (bottom left), and it is completely invisible on the clockwise inspection.

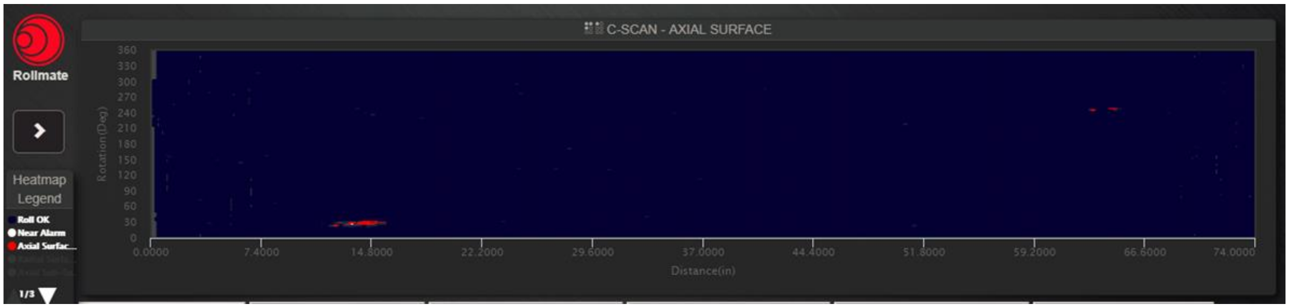

Fig. 11. Axial Inspection Result - Counterclockwise

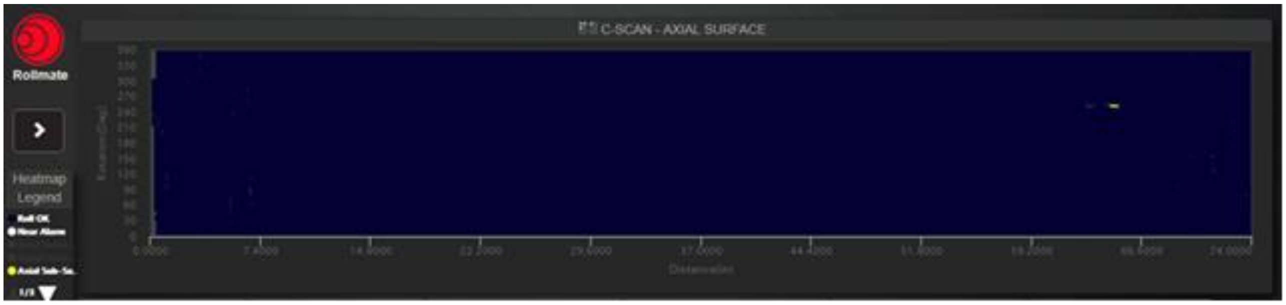

Fig. 12. Axial Inspection Result - Clockwise

After further analysis with a handheld UT instrument, it was observed that the angle of the crack allowed the sound to be reflected in one direction but not the other. As per the drawing below, the sensor A pointing counterclockwise detects the slanted defect whereas sensor B (located in the same head but pointing in the opposite direction) does not detect the defect.

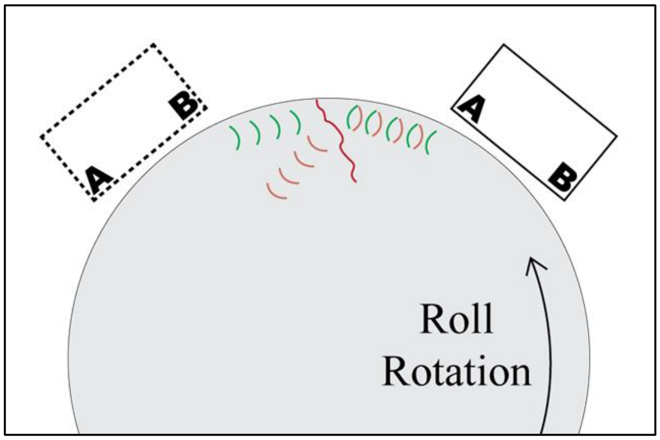

Fig. 13. Effect of Crack Orientation on Defect Detection

CONCLUSIONS

When challenged to develop a new generation of mill roll inspection systems, Innerspec embraced the task and sought to design a comprehensive solution using the best NDT techniques available for the task.

After several years of analysis, design, and thorough testing in the laboratory and in a roll shop, Innerspec has designed a system with no compromises on detection capability or quality; the new Rollmate G3 detects all the defects that could cause problems in a mill, regardless of geometry, location in the roll, or whether they were created during the manufacturing process or during rolling in the mill. It is also designed to inspect any type of roll, forged or cast, with any metallurgical composition and from any manufacturer, with minimum calibration requirements and user involvement.

The system is fully designed and manufactured in the United States, and serviced and supported by Innerspec offices in the US, Mexico, Europe and China.

REFERENCES & ACKNOWLEDGMENTS

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