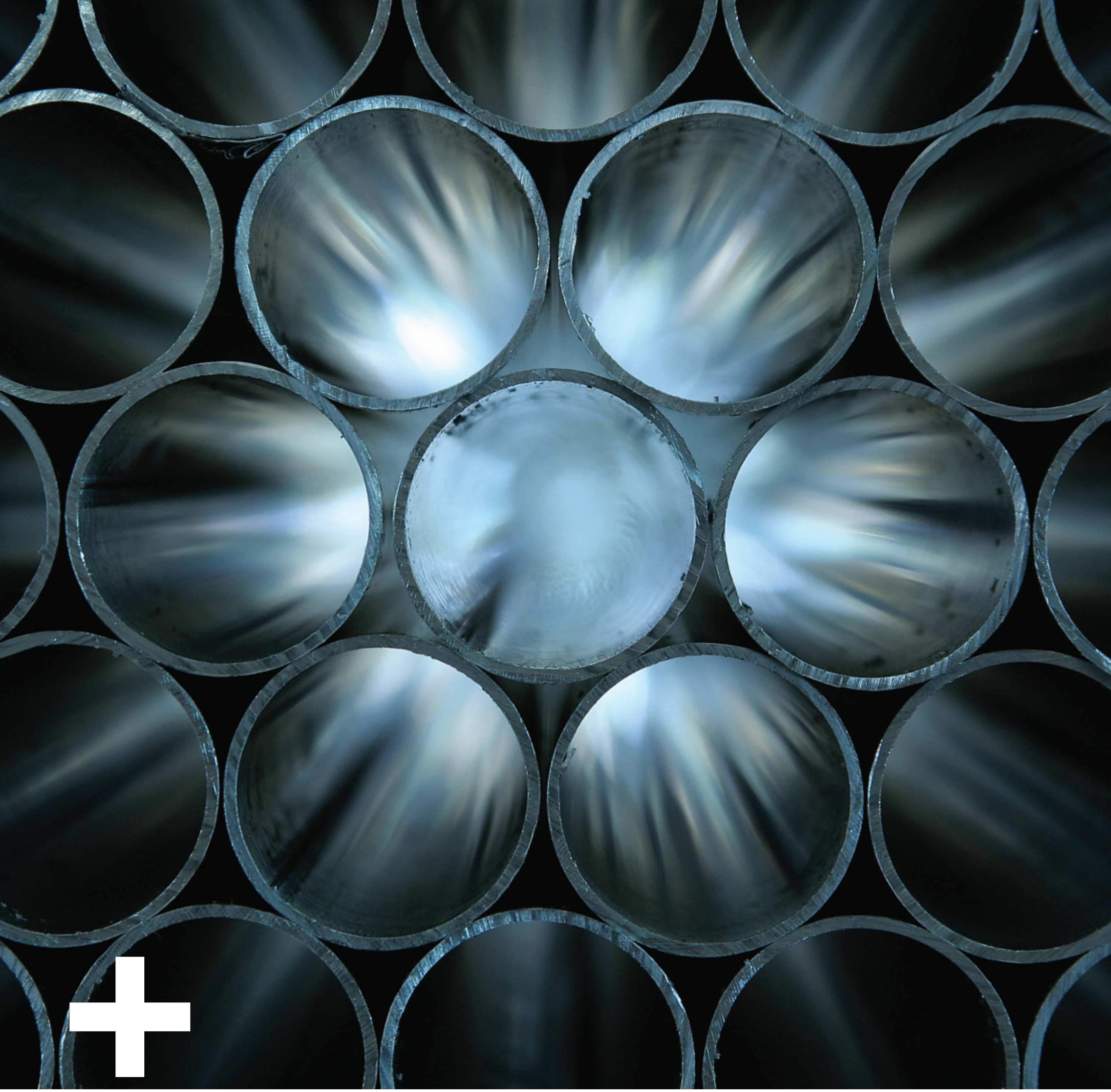


Non-Destructive Inspection of
Tube and Pipe Welds

XIRIS
Inspection Solutions with Vision

Tube and pipe fabricators have been improving quality and reducing scrap with Non-Destructive Testing (NDT) for many years. The traditional NDT methods—Eddy Current Testing (ECT) and Ultrasonic Testing (UT)—both allow for in-line testing of formed and welded tubes and pipes, enabling operators to detect numerous weld defects and discontinuities, at various mill speeds, so those quality issues can be corrected.

But as powerful as they are, ECT and UT:

> Are somewhat complex to set-up.
> Are sensitive to external conditions in the mill.
> Require multiple probes to obtain reliable data.

And even if these challenges are sufficiently addressed, ECT and UT still can't detect or classify some critical weld defects on Tube and Pipes.

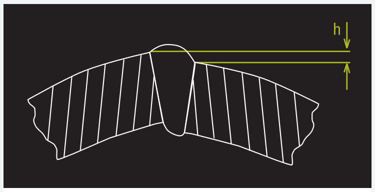
Common Profile Defects That Are Missed By ECT & UT

Mismatch

The mismatch defect is caused by uneven joining of two halves of the tube material before welding. Mismatch is a vital parameter to monitor for all tube and pipe fabricators regardless of which side is higher—because many mills employ a grinder or scarfing tool to grind or scrape away any excess bead that is out of round. If there is mismatch prior to welding, once the tube bead has been removed, part of the wall on the high side of the mismatch may get removed as well, causing significant thinning of the tube wall after grinding the weld area.

Also, sometimes even without grinding, the actual welded tube wall thickness in the area of the bead becomes smaller than the original tube wall thickness as a result of additional processing steps such as corrugation or bending of the tube, creating additional potential failures.

Mismatch is calculated as the absolute value of the radial difference between the two reference points where the weld bead meets the parent material. The mismatch calculation uses the current roll angle to compensate for the bead roll.



Mismatch Defect

Laser-Based Non-Destructive Inspection

A solution to the shortcomings of traditional NDT has emerged: laser-based Non-Destruction Inspection (NDI) of the weld bead on formed and welded tube pipes. Made possible by advancements in machine vision technology, laser-based NDI can be used on tube or pipe mills as a complement to traditional NDT to find specific weld defects related to the surface profile of a weld, resulting in improved quality assurance and process control.

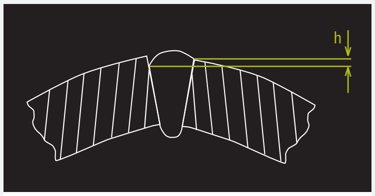
By measuring the outside contour of a weld, an NDI system can operate on any type of material, regardless of its reflectance or magnetic properties, using a single head to perform the measurement.

Very often NDT systems are installed as a final check at the end of the production line. However, an NDI system can be placed directly after the weld box, where it can be used in a more proactive manner, warning operators what is changing in their welding process so that they can perform corrective action before significant scrap occurs.

Xiris Automation Inc. has developed an NDI system, the WI2000 Weld Inspection System, which is based on triangulation measurements captured using a laser plane and a camera whose optical axis is offset to the axis of the laser plane (by the "offset angle").

Undercut

The undercut defect, primarily a result in laser welding processes, may form if the laser beam is too far off center of the ideal welding zone of the tube material. Undercut is actually a non-welded area of the bead on one or both sides of the bead. It looks and behaves like a crack along the bead, creating a very weak point on the tube cross-section. Undercuts are detected as sharp, narrow negative drops in the actual profile (at least one side of the undercut must have high deflection derivative) that happen close to the edges of the bead. The absolute value of the biggest negative drop found is reported as an undercut.

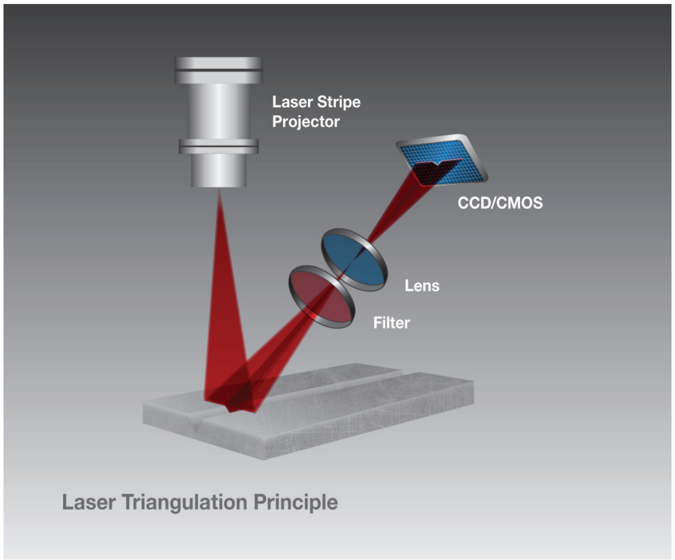


Undercut Defect

Bead (Raised or Sunken Welds)

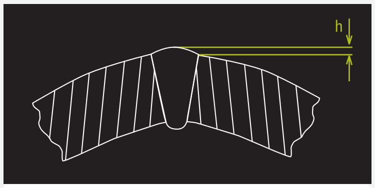
The material in the bead area may rise on top of the tube surface ("raised weld") or drop below it ("sunken weld"), depending on the compression force and the laser beam size.

The sunken weld defect is a visibly significant defect that could create weakness in the tube along the bead. While the raised weld defect may not be considered an important defect (as it can be ground off later), it can indicate quality problems in the welding process.



The WI2000 creates a visible cross-section of the tube by projecting the laser line on to the tube and capturing an image of the line using the camera. The resulting image shows a "cut-away" profile of the top section of the tube as if it was cut at the offset angle to the normal of the tube surface. If a tube is ideally round, the laser image will represent a section of an ellipse.

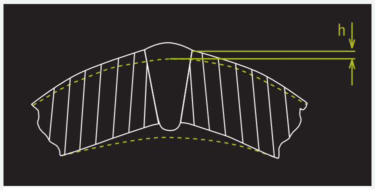
The bead metric is defined as the largest absolute value of a raised or sunken weld. Calculating the bead metric in this way helps to determine the height of the tube material that needs to be ground off to smooth the profile (and restore the cylindrical shape, as required). In case of additional mismatch, the bead metric will include the mismatch and will report the total loss of the material thickness after grinding.



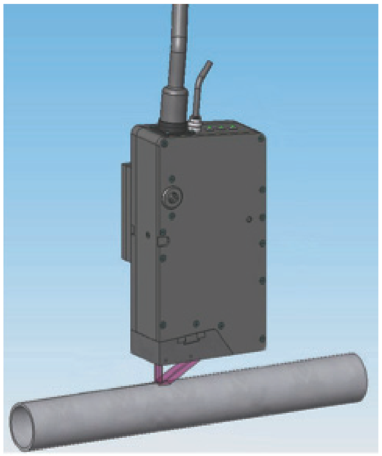
Bead Height Defect

Deflection

The overall deflection of the tube material from the ideal circle moves the starting point of all other defects up or down. The deflection measurement detects the overall deflection from the ideal circle to the closest tube side within the bead area. The deflection metric is determined by measuring the distance between the flat sections outside of the bead and the ideal profile line. The deflection usually represents the overall offset of the tube walls before welding.



Deflection Defect



WI2000 Mounting Relative to Tube

The WI2000 bases all of its measurements on the differences between the actual laser profile line seen by the camera (formed as a line joining the midpoints of the laser profile image) and the ideal mathematical profile. The tube diameter determines the length of the ideal profile line to be fit over the actual profile line.

By knowing the position of the actual laser profile, the ideal profile, and the size of the pixels in the image, the WI2000 can calculate various profile defects that often escape detection by ECT and UT, including:

> Mismatch.
> Undercut.
> Bead height (raised or sunken welds).
> Deflection.
> Bead roll angle.
> Freeze line.
> Scarf width.
> Left/Right slope angle.
> Bead width.

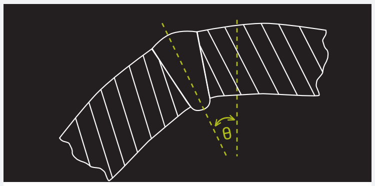
Defect Measurements Shown on Xiris WI2000

Bead Roll Angle

Due to the round profile of the laser and the tube, the reported metrics from the WI2000 must consider the position of the weld bead relative to the ideal vertical (or centerline) position of the profile. The nature of some welding processes such as Laser Beam Welding (LBW), the weld bead is required to stay within fixed and narrow range around the vertical position to ensure the best quality weld. The bead position cannot change momentarily or a bad weld will result. In normal actual processes, it takes up to 10 seconds to significantly move the bead from the vertical position to several degrees off vertical.

As a result, the system uses the bead position as a reference point to locate all other measurement tools, and requires the setup of the weld head so that the actual bead area is as close to the center of the image as possible (roll angle must not exceed 1.5°-2°). It is therefore essential to accurately find the center of the bead for all other inspections to function properly.

The bead roll angle is averaged using a number of successive images. As a result, the WI2000 system obtains stable measurements for the roll angle value that changes slowly over time—allowing for correct positioning of all the other measurement points to occur even during significant roll of the tube.



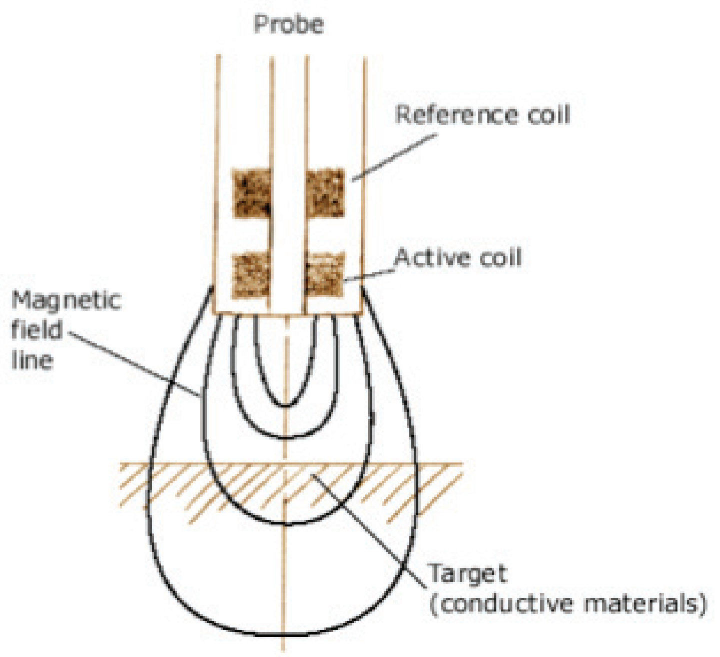
Bead Roll Defect

The Limitations of Non-Destructive Testing

Both ECT and UT are capable of finding many defects on tube and pipe mills, but they are inadequate for measuring the several common defects.

Limitations in Eddy Current Testing

The typical ECT system uses the deflection or disruption of a closed-loop pattern generated by the alternating electrical current induced in the electrically conductive pipe material to detect the weld defects (pinholes, cracks, etc.). The precision of detecting these defects is significantly impaired by this "noise".

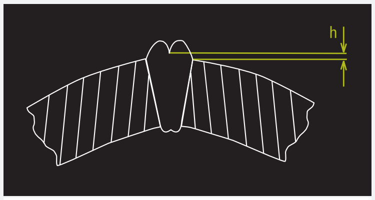


The Eddy Current Process (courtesy www.efunda.com)

Freeze Line

Particularly in Electric Resistance Welding (ERW) or High Frequency (HF) welding processes, incomplete heating of the faces of the parent material can sometimes occur, resulting in a potentially cold-welded joint, which manifests itself as a line or seam extending from the top surface of a weld down into the welded area, in the shape of a sharp valley. Such a defect could indicate major metallurgical or structural problems in a weld, such as cold welding or improper forming. It can very often be a point of a major failure of a weld in high-stress applications because the freeze line acts as a crack initiator into the welded material.

The WI2000 system detects the presence of any freeze line that goes a pre-defined distance below the surface of the parent material as defined by the ideal circle scribed by the walls of material beyond the weld zone.



Freeze Line Defect

ECT systems are also difficult to set up and calibrate for achieving repeatable inspection results because of:

- The sensitivity of the eddy current probes to variations in test frequency.
- Coupling factors.
- The relationship between inside and outside pipe diameter.
- The electromagnetic characteristics of the material itself.

Additional DC field magnetization using segmented, all-round permanent or electromagnetic magnets that surround the test coil (housed in special DC magnetization test coil holders) are needed to magnetize the tube at the point of test.

ECT systems typically operate in two modes:

1) Absolute sensing, where the inspected pipe section is compared with a "learned" pattern stored in the system's memory. This mode provides a continuous signal for full-length open seams but has a limited sensitivity due to noise generated by roll marks and un-relieved stress in the material.

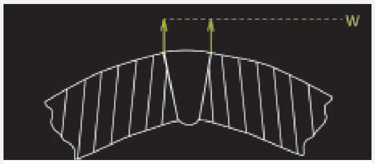
2) Differential sensing, where the inspected pipe section is compared with the section immediately preceding it. This mode provides high sensitivity to short or intermittent defects but often misses a continuous defect because
it doesn't modulate along the length of the tube).

In either mode, there are other defect types that are often missed by ETC, including mismatch (or registration), undercut or overcut welds, scarf width, pinholes, weld embrittlement, and poor-diffusion (pasty) welds.

Scarf Width

In certain situations on ERW/HF tube and pipe production lines, there's not enough space to perform the NDI measurements right after the weld box because the scarf tool (used to remove excessive bead from the tube) is placed directly after the weld box. In such situations, the measurement process must be made after the scarfing tool, measuring the flat area of the tube where the scarf has occurred. On some production lines, this measurement is essential to identify the shape and profile of the tube, and to understand how it is travelling through its forming process.

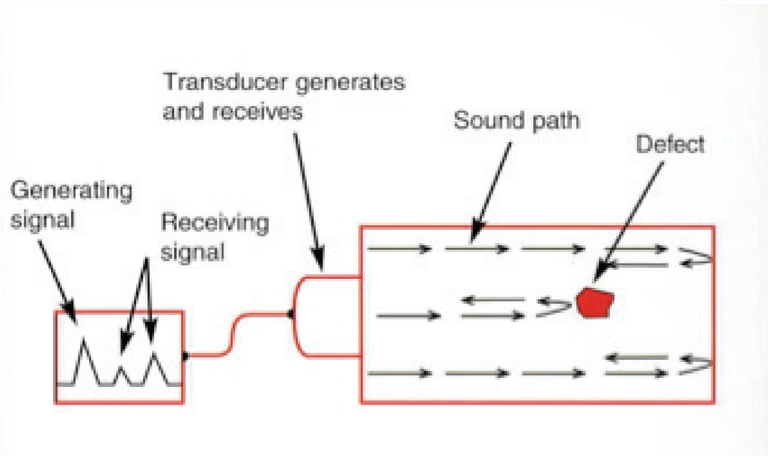
Known as the scarf width, this measurement is defined as the length of the "flat" portion of the tube that appears after the weld bead has been removed by scarfing. Scarf width measurement changes quickly during production, so it is best averaged over a number of inspections in order to make the measurement stable.



Scarf Width Defect

Limitations of Ultrasonic Testing

The typical UT method detects surface and internal irregularities in ferrous and non-ferrous metal welds by transmitting high-frequency pulsing sound waves through the weld, and bouncing back to a transducer, with the results being transmitted to a monitor as a trace. If the acoustic pulse comes in contact with an irregularity in the weld, the waves are sent back to the transducer and show up on the monitor screen. The defect can be placed very accurately, but it requires an experienced operator to interpret the tracings on the monitor.



Ultrasonic Testing Principle (courtesy www.ndt-ed.org)

UT testing also requires a number of ultrasonic probes to be placed around the pipe—the actual number varies as a function of pipe geometry, the production process, and the pipe usage, and often require a liquid to couple the probe to the tube or pipe. Larger pipe diameters and higher production speeds will typically require more ultrasonic probes.

Left/Right Slope Angle

The Left and Right Slope Angles are measured in degrees at either edge of the weld bead and represent the angle subtended by a line that follows the contour of the weld bead on either side and a horizontal line. Also referred to as the toe angle, it can indicate the strength of the weld and the correct forming of the parent material of the pipe during the creation of the weld, particularly on an ERW/HF process. A forming problem could be detected by a larger or smaller than normal slope angle.

It is important to measure both the left and right slope angles separately because the forming of the parent material could be asymmetric on a pipe mill, causing the slope angles to be different on either side of the weld bead.

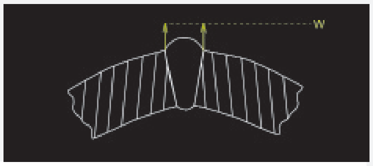
Left/Right Slope Angle Defect

Detection methods vary depending on the type of defect inspected. Ultrasonic probes must be located differently for detection of longitudinal, transverse, or lamination type defects, implying that a large amount of costly equipment is needed for the complete testing of tube and pipe welds. Still, many defects are often missed by UT, such as mismatch, scarf width, deflection, bead roll, bead width and bead slope angle.

Bead Width

The Bead Width is a linear measurement across the profile of the bead, measured from the inflection point between the parent material and the edge of the bead on either side of the bead.

The Bead Width is affected by a number of parameters such as weld temperature, squeeze pressure, metallurgy, shielding gas and a variety of other parameters.



Bead Width Defect

Using Laser-based NDI to Overcome NDT's Drawbacks

Laser-based NDI provides a solution to many of the NDT's technical shortcomings, such as:

> **Sensitivity to external conditions that can influence the measurement's precision.** The ECT and UT systems' precision is influenced by coupling factors between their probes and the tube, the relationship between the tube diameter and defect location, and the electromagnetic characteristics of the material itself. Laser-based NDI isn't sensitive to these external conditions.

> **Requirement for multiple probes to obtain reliable measurement data in real time.** Statistics show that the weld area itself is most prone to defect presence, so the logical positioning of the probe should be in the heat-affected zone (HAZ). NDI systems such as the WI2000 use a single sensor to acquire images of the tube's weld profile at the HAZ, compared to the several probes required for most ECT and UT systems to ensure the HAZ is covered.

> **Inability to measure gradual changes.** NDI systems such as the WI2000 are able to make complete, absolute measurements of the contour of the weld in real time without comparing a measurement to a successive measurement. Therefore, those defects that gradually move out of tolerance are best detected with NDI systems, whereas UT or ECT systems will only detect something if there is a sudden anomaly in the tube structure or geometry.

> **Inability to make qualitative or quantitative measurements**. Laser-based NDI systems generate an image of the profile of the tube contour and are therefore able to determine when a tube welding process is out of control—providing detail as to which feature is out of control and by how much. This ability, which UT and ECT don't have, allows for better process control.

> **Difficult installation and set-up.** On a typical tube mill, there is often some roll in the weld seam from side to side, and both UT and ECT systems are very sensitive to the position of the weld seam. Therefore, they require precisely located probes in relation to the point of inspection of the weld. Due to its ability to detect weld quality with the same resolution, anywhere in its field of view, the WI2000 acquires an image of the profile and can keep operating even if the weld moves back and forth (i.e., "rolls").

Conclusion

While laser-based Non Destructive Inspection (NDI) systems are powerful defect detection systems, they are not a complete replacement for either ECT or UT systems, which can still provide certain inspections beyond the contour of a weld.

However, because NDI systems don't have many of the inherent technical limitations of ECT and UT, an NDI system such as the WI2000 offers an excellent option for pipe and tube mill fabricators to improve weld quality and efficiency. By offering real-time defect detection of weld features beyond what traditional NDT systems can provide, NDI systems can lower scrap and production costs, providing tube and pipe fabricators with a valuable competitive advantage.

Would you like more information?

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