Choosing the Proper Nondestructive Testing Techniques

Donald N. Bugden

Magnetic Analysis Corporation, Mt. Vernon, NY, USA

Phone: (914) 699-9450, Fax: (914) 699-9837; e-mail: info@mac-ndt.com

Abstract

This paper will concentrate on the three nondestructive testing methods – namely, eddy current, ultrasonic and flux leakage, which are the predominant methods used in the steel tube industry for flaw detection, while recognizing the role of pressure related or mechanical proof testing. The advantages and disadvantages of the three methods are reviewed. In the past, this type of comparison was made when choosing which of the three methods to apply, but as demands for quality increase and multiple methods are used, it has become necessary to combine and locate these methods in the manufacturing process so as to produce a complimentary and flexible system, rather than mere redundancy. One outcome that seems to come to light from this discussion is whether the nondestructive test procedures that pertain to steel tubing, and which tend to be exclusive for the various methods, and thus encourage redundancy rather than synergy, should be reviewed and subsequently revised.

Keywords: nondestructive testing, eddy-current, ultrasound, flux leakage, tube, defect, flaw, API, ASTM, DIN

Tubing Considerations

The tube buyer requires tubing that will perform as required, so as to conform to any applicable regulations and diminish the specter of product warranty or personal liability claims. He will attempt to satisfy this requirement as economically as possible. Some of the issues that must be considered by the buyer are:

- The end use of the tubing
- Grade or alloy chosen
- Seamless or welded
- Cold finished or not
- Mandatory nondestructive test specifications
- Documentation

Supplements to Flaw Detection:

- Grade mix protection
- Demagnetizing
- Dimensional measurement
- Proof testing
- Mechanical sampling

Typically, the types of tubing chosen by the end user will be based upon considerations that take precedence over the eventual nondestructive test methods chosen. Since this first choice has considerable impact upon the effectiveness of the method that is eventually applied, there is a need to factor in the nondestructive test options early in the decision process. Since the tube buyer depends to a great extent upon the advice of the tube manufacturer, the increasing interest and level of sophistication of nondestructive personnel at the tube mill in the subtleties of the various methods is important, and must be supported by the manufacturers of nondestructive test systems. The major needs of the tube manufacturer derived from the tube buyer can be listed in the following way:

- Compete in quality and price
- Meet industry and customer specifications
- Maintain maximum yield
- Limit testing cost
- Satisfy diverse clientele

Choosing the proper NDT technique

As can be seen from the abbreviated list in Table 1, which is far from being all-inclusive, we are already confronted with a huge combination of variables. The choices made, in terms of product parameters, have a profound influence upon which type of product deviations are likely to occur. Furthermore, these variables must be reconciled with the capabilities of the various methods that are listed, in a general way, in Table 2.

Except in those cases where an elaborate request for quotation is prepared, - usually limited to large and expensive systems – many of the factors listed previously that greatly influence the long term costs of providing nondestructive testing are not taken into account in the buy decision. Very often the tube manufacturer looks for the lowest capital investment that will comply with the NDT Specification chosen by the tube buyer. Although this may sometimes be the best decision, there are a number of questions that the tube manufacturer should consider before making that assumption.

First of all, even if the most appropriate nondestructive test procedure seems to be specified, which is not always the case, it will not guarantee the detection of all natural defects that may cause a service failure. Since the tube manufacturer will feel some impact from the failure, if not in the case at hand perhaps in the loss of a customer, the choice of NDT Specification should be evaluated with the types of defects that are known to occur, as well as the strengths and weaknesses of the various nondestructive test methods in mind. This is especially true since the various specifications pertaining to the testing of tubing leave considerable leeway in choice and application of method. Even when a specific method is called out, certain test parameters may be left to the tube manufacturer, or can be negotiated with the tube buyer.

A second important consideration is the effect on yield of the method or the particular apparatus within a method that is chosen. This can have a dramatic effect on reject rates. The ideal method or combination of methods would reject only those conditions that will result in service failure. Although this ideal cannot be totally achieved, the extra investment in improved systems that are becoming available may very well show a very short return on investment from increased yields because of the test equipment's ability to come close to making the important distinction between detrimental and innocuous deviations.

Another set of decisions with considerable cost implications is where to place the nondestructive test system in the production flow. The simplistic answer would be to place the system as close as possible to the operation that will be the last source for defects. In the case of a welded tube mill, where the tubing is used in an "as welded" condition, a fairly common situation, this solution is achievable and the choice of a method, for instance, eddy current, may be clear-cut.

However, even here complications can arise. If the specification calls for two methods, as may be the case for gas distribution lines, and hydrostatic testing is chosen as the second method, the specification may require that the nondestructive test be done after the hydrostatic on the premise that the hydrostatic may open up pasty or incomplete welds. The same concern would apply in a structural welded tube mill set up to produce either rounds, as a final product, or to be fed into forming rolls down steam in the mill where it is formed into shapes. Here again, defects that are not detected immediately after welding may be enlarged by the cold forming, and the test station should therefore follow the forming operation.

As the number of operations where defects can be created increases, the potential sites for nondestructive test stations expand accordingly, and the benefit of multiple tests at different locations needs to be explored. For instance, in the case of cold drawn and annealed heat exchanger tubing that is produced from welded stock, the nondestructive test method is generally applied as the final operation before packing. By that time, defects produced on the weld mill that could have been detected there may result in an inordinate reject rate at the final NDT inspection. For this reason, many manufacturers have installed eddy current or ultrasonic weld zone inspection on the weld mill as a process control, and satisfied the requirement for full body inspection at a final test station.

Another important factor affecting cost is the need for an exclusive certified nondestructive test operator at the final inspection station, as opposed to an automatic system as is the norm on a weld mill or straight and cut machine. This cost is affected not only by the time operating the NDT system, but by the time taken for size changeovers. Generally, eddy current changeover is simpler and faster than ultrasonic of fringe flux devices, but in all cases added capital investment in computer based systems, that return to previously obtained instrument settings for each product size, offer the possibility of reducing operating costs. When obtaining the original setup of instrument settings is time consuming, as for instance in the case of multi-channel inspection of boiler tubing, and where lot sizes may be very small, the investment in sophisticated eddy current or ultrasonic computer based instrumentation that recalls setups and produces documentation may be justified. Conversely, in the case of weld line inspection for process control on the welder, where size changeover is infrequent and the time to change the mill substantial, simpler, less expensive analog instrumentation with automatic alarms may be sufficient.

The maximum throughput speed that will achieve one hundred percent coverage by the system chosen will obviously have an impact on costs. If the test is in-line, and a dedicated nondestructive test operator is not necessary, the method must be able to keep up with the speed of the production line in which it is located. In the case of off-line inspection, bottlenecks cannot be tolerated and faster throughput speeds of a particular test system will limit the number of systems required, and the operating time on each.

As a general rule, eddy current is considerably faster in throughput speed and changeover time than the other methods. Fringe flux leakage would probably rank second, with rotating head ultrasonic next, and rotating tube ultrasonic the slowest. In the case of ultrasonic systems, throughput speeds are further improved by adding replicated transducer sensors to maintain coverage at higher speeds, but of course it requires a higher initial investment.

Although an eddy current system generally would be the least expensive system to acquire and operate, stretching the application beyond its inherent capability can be costly. Most eddy current specifications are calibration holes and notches which are easily detected without false rejects on diameters less than four or five inches, and wall thicknesses below .250 inches. On larger diameters, finding the same notch often increases the number of false indications and in the long run, increases the overall cost of nondestructive testing. Calibrating an eddy current system on longitudinal inside diameter notches, except on small diameter light wall heat exchanger tubing, may produce false reject levels which are intolerable and make ultrasonic testing a less expensive overall choice. In fact, heat exchanger tubing and boiler tubing are increasingly being subjected to eddy current and ultrasonic inspections.

Although the latitude in the various nondestructive testing specifications is good when there is a cooperative effort between the tube buyer and his supplier to answer the need with an adequate product at a fair price, this room is meant to enhance the ability to match the tubing supply to the need as economically as possible. Sometimes it is used in a way that results in the attempt to use a method beyond its capability, as described in the previous paragraph. If the calibration standards are appropriate for ultrasonic inspection, but the specification allows eddy current inspection, competitive bidding by tubing suppliers may eventually be detrimental to the buyer, whose own interests would be better served by paying an additional charge for the proper test. Ironically, the buyer would also be better off if he specified a nondestructive test method and calibration procedure that would satisfy his needs, rather than attempting to obtain a more stringent inspection than is necessary at a bargain price. It is also incumbent upon the tube producer to inform his customer accurately about the realities of nondestructive testing choices, and hopefully persuade him to make the best one.

It was mentioned earlier that applying the existing ultrasonic and eddy current specifications separately to each method when they are both used on the same order should probably be reviewed. An example would be in the case where both methods are applied as a final inspection to heat exchanger tubing. An eddy current line for that product would provide one hundred percent coverage at speeds of 400 feet per minute or faster while a rotating head ultrasonic system might provide one hundred percent coverage at speeds around 150 feet per minute. Keeping in mind that the ultrasonic test is added to find long, continuous defects that may be missed by the eddy current, it would seem appropriate in some cases to run the line at higher speeds than dictated by the ultrasonic specification if it can be demonstrated that the eddy current will detect the short defects that may fall between the helical pitch of the ultrasonic scan.

It would be impossible to cover even a small fraction of the unique considerations that arise in particular nondestructive testing relationships. Perhaps the examples cited will persuade the industry that there is a vast amount of knowledge that can be brought to bear upon these decisions when the interested parties realize their scope and discuss the options thoroughly. It is also hoped that the industry, through the various professional institutions that bring together this background in the form of nondestructive test specifications and procedures, will continue to review and adjust these documents as NDT apparatus and practices improve, both as separate techniques and in combination.

TABLE 1 - FACTORS TO CONSIDER IN SELECTING NDT TECHNIQUE FOR YOUR APPLICATION

END USE	MANUFACTURING PROCESS	POSITION and MECHANICAL CONDITIONS	NDT MEASUREMENT TASK	NDT EVALUATION TASK	APPLICABLE PROCEDURE	COSTS
Fluid Transmission Heat Exchanger Pressure Hydraulic Gas & Oil Mechanical Force Transmission Cylinder Tubing Hot Forming Stock Cold Forming Stock Machining Stock Structural Ornamental Furniture Medical	Welded Longitudinal or Spiral, Electrical Resistance Weld, Induction Weld, High or Low Frequency AC or DC Continuous Weld, Tungsten Inert Gas, Electron Beam, Laser Beam, Bead Condition: None, Scarf, Hammer, Roll In Line Annealing Butt Welding Seamless Continuous Casting or Ingot Piercing Extrusion Finishing Operations Hot stretch Reduce Pilger Mill Rotary, Roll, Stretch, Straightened, Pickled & Shotblast, Sinking, Plug Drawn, Drawn Over Mandrel, End Chamfer, Upset End, Threading, Heat Treating & Annealing	Diameter & Wall thickness, Shape, Straightness, Roundness, Surface condition, End Condition, Cleanliness, Temperature, Metallurgy	Flaw Detection Minimum detectable size Geometry/ Orientation: Short or Continuous, OD, ID, Midwall, Longitudinal, Transverse, Oblique Natural Defects: Weld Skips, Incomplete Weld, Hook Cracks, Lamination, Inclusions, Metal Separation, Mechanical Cracks, Open welds, Butt Welds, Weld Bead Variance, Weepers, Pastey weld Dimensional Measurement Wall thickness, Outside Diameter, Inside Diameter, Wall Variations, Ovality, Straightness	Defect Marking Reject Sorting Documentation: Calibration & Setup, Defect Count by type, Defect location by type, Defect Severity by type SPC Trends	ASTM MIL DIN API	Operating Costs Yield Level of Automation Personnel Skill Level & Certification Changeover Time, Utility Costs, Maintenance & Calibration, Maximum Throughput Speeds, Location of Test or Tests, Purchase or Lease, Service Contracts Investment Costs Choice of Method or Methods, Tooling Costs, Peripherals, Adaptability, Future Flexibility, Location of Test or Tests, Purchase or Lease

TABLE 2 - FACTORS TO CONSIDER IN DIFFERENT TEST TECHNOLOGIES

TEST METHOD					
EDDY CURRENT (1)	TYPICAL APPLICATION	DEFECT CAPABILITY	TYPICAL LOCATION	TYPICAL THROUGHPUT SPEED LIMIT	RELATIVE COST (5)
Full Body Encircling Differential Coil	Ferrous & nonferrous Cold Finished Welded & Seamless (.050” D x .004” Wall) to 7.5” D x .400” Wall	**Excellent** for Short, small defects, Pinholes, Weld skip, Slivers, Transverse, Metal Separation or Cracks. **Poor** for long defects, Incomplete ID Welds, Lamination, Stringers, Laps, Seams, Longitudinal cracks	Operator tended, Off-Line with automated conveyor In-line on Weld Mills, Straight and Cut Straights	Easily accommodates normal mill requirements up to 1000 FPM Low speed on TIG welding Heavy Wall requires special adaptation	
Ancillary Encircling Absolute Coil	Same as Above	Some capability on Gross, Long Defects such as open weld	Same as Above	Same as above	High
Weld zone Segmented Differential Coil	Ferrous & Nonferrous as welded (1” dia x .0?? Wall to 20” dia x .400 Wall)	Excellent for Short Defects, except very small weepers	Weld Mill	Same as Above	Usually non tended with automated defect recording, marking & test result reporting

TEST METHOD					
EDDY CURRENT (1)	**TYPICAL APPLICATION**	**DEFECT CAPABILITY**	**TYPICAL LOCATION**	**TYPICAL THROUGHPUT SPEED LIMIT**	**RELATIVE COST (5)**
Ancillary Segmented Absolute coil	Same as Above	Continuous Open Weld	Weld Mill		
Grade Sorting	Boiler Tube, Mechanical tube (up to 7.5" dia)	Will sort, but not identify grades or heat treat variances	In tandem with NDT flaw system	No Limit	Very low cost

FLUX LEAKAGE	TYPICAL APPLICATION	DEFECT CAPABILITY	TYPICAL LOCATION	TYPICAL THROUGHPUT SPEED	RELATIVE COST (5)
Full Body (2)	Ferrous Hot Rolled Seamless Welded Cold Finished (2 5/8” Dia x .100” Wall to 20” Dia x .600” Wall) Extensive Use on O.C.T.G.	Better than EC for ID Defects on Heavier Wall Thickness, Short and Long Defects Good OD Detection of Longitudinal Defects OD – 5% of Wall Thickness in Depth ID – 12% of Wall Thickness in Depth	Operator Tended, Off-Line with Automated Conveyor	Up to 400 FPM Very Dependent upon diameter and length	Moderate to High, Depending on Product Size
Full Body (3) Longitudinal Magnetization (Segmented Sensor Array)	Same as Above	Transverse Defects	In-Line with Above	Same as Above	Moderate Addition
Weld Zone Transverse Magnetization	Ferrous as Welded Field Inspection	Short Defects, Not as good as UT, but does not require couplant (water)	Weld Mill	Same as Above	Moderate

ULTRASONIC (4)	**TYPICAL APPLICATION**	**DEFECT CAPABILITY**	**TYPICAL LOCATION**	**TYPICAL THROUGHPUT SPEED**	**RELATIVE COST (5)**
Full Body - Rotating Transducers	Ferrous & Nonferrous Seamless and Welded Hot or Cold Finished Light to Very Heavy Wall Thickness ¼” to 5” 2” to 7” 2” to 10”	Longitudinal and Transverse Defects, Short or Continuous Better than EC or FL on ID Stringers, Inclusions, Incomplete Weld, Hook Cracks Tapered Defects Response very dependent upon defect orientation in relation to transducer orientation	Operator tended, Off-Line with automated conveyor	Depends upon length of notch specified	Depends upon size of product, number of measurements, and system location and level of automation and throughput speed required Moderate to High High
Full Body Rotating Tube	¼” to 5” 2: to 7” 2” to 20”	Same as Above	Off-Line with specialized conveyor system for spinning the tube	Very dependent upon diameter and length of product. As a rule, slower than rotating head systems	Moderate to High High Very High
Weld Zone	1” and above Any wall thickness	Same as Above	Longitudinal and Spiral Weld Mills	Dependent upon wall thickness, but able to keep up with welding speeds	Moderate
Dimensional UT		Wall Thickness OD and/or ID Wall Variation Ovality Weld Bead Monitoring	Auxiliary to Flaw UT	Same as Above	Low to High depending upon number of measurements

MECHANICAL TESTING	**TYPICAL APPLICATION**	**DEFECT CAPABILITY**	**TYPICAL LOCATION**	**TYPICAL THROUGHPUT SPEED**	**RELATIVE COST (5)**
	As welded in all sizes	Pasty weld, Visual Weld Defects	Tube Mill	No restrictions	Very low

PROOF TESTING	**TYPICAL APPLICATION**	**DEFECT CAPABILITY**	**TYPICAL LOCATION**	**TYPICAL THROUGHPUT SPEED**	**RELATIVE COST (5)**
Hydrostatic Air under water Leak testing	Welded and seamless heat exchanger tubing	Pasty weld Very small weepers	Final inspection	Normal Producing speeds	Very High Labor intensive

Notes:

(1) Typical calibration specifies small drilled hole and/or transverse outside diameter notch.
(2) Typical calibration specifies 1/16” or 1/8” diameter drilled hole and/or 1” or 2” long longitudinal outside diameter and inside diameter notches, 12% of wall thickness in depth
(3) Typical calibration specifies 1” or 2” long transverse outside diameter and inside diameter notches, 12% of wall thickness in depth
(4) Typical Calibration specifies .030” to 1” long longitudinal and transverse notches, 3% to 12% of the tube wall in depth. For some API specifications, oblique notches at two 45 degree orientations are added to longitudinal and transverse notches.
(5) Relative cost: Low – Less than $50,000; Moderate - $50,000 to $200,000; High - $200,000 to $500,000; Very High – above $500,000.