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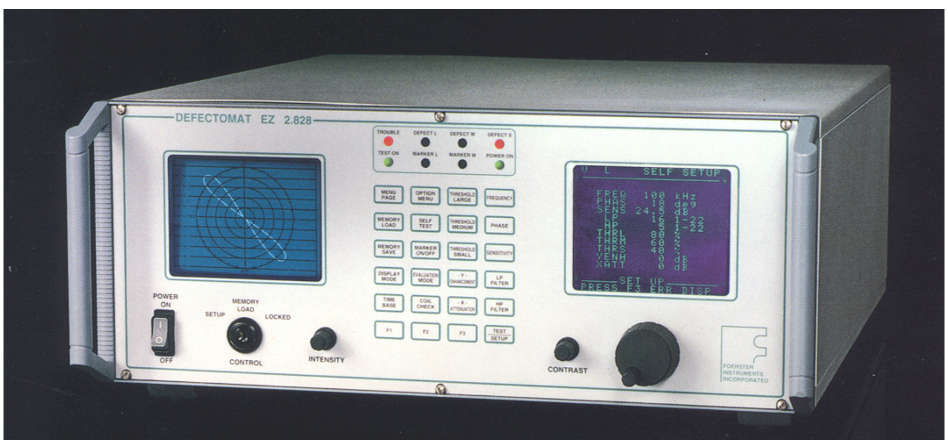
I N C O R P O R A T E D

Techniques for Detection of Surface Defects in Tubing and Pipe



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Abstract

Ferrous and nonferrous tubing and pipe are used in a large number of applications where the presence of O.D. and I.D. surface defects can have a detrimental or even catastrophic effect on the serviceability of the structure or system. The electromagnetic non-destructive testing methods of eddy current and magnetic flux leakage inspection offer tubing and pipe manufacturers the opportunity to detect the defects either during or immediately following the manufacturing process. Early detection helps to assure that the manufacturer will supply quality tubing and pipe to the market.

There are a wide range of applications involving electromagnetic inspection of tubing and pipe. Processing speeds can vary from less than ten to nearly two thousand feet per minute. Different ferrous and nonferrous materials each have their own unique characteristics, failure modes and processing methods. Inspection environments can vary from a high temperature piercing mill to a relatively clean off-line inspection station.

The electromagnetic inspection system must be adapted to the specific application. Various test coil systems, signal processing techniques, and evaluation methods are utilized depending on the application. With proper equipment selection, installation and operation of a reliable testing system can normally be established.

1 Introduction

Many international standards exist to define the requirements of tubing and pipe. One such set of standards are those that are published by the American Society for Testing and Materials (ASTM). These standards generally define the required properties of the finished products and include such attributes as dimensional tolerances, mechanical properties, metallurgical properties, surface quality, and, in the case of welded tubing, weld quality. The product specifications normally make reference to the documents that describe the standard practices that describe the applicable test method.

Electromagnetic nondestructive encircling coil testing is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and, magnetic permeability of the tube material, and metallurgical and mechanical discontinuities in the tube.

The testing system is usually calibrated using a reference sample consisting of a representative sample of material containing one or more artificial discontinuities. The size, type, location, and orientation of the artificial discontinuities are described in the applicable product standard.

This paper will focus on the electromagnetic nondestructive testing with interpretation of the requirements set forth in ASTM specifications for three types of products:

Copper tubing

Steel pipe and tubing

Austenitic pipe and tubing

2 Copper Tubing

Copper tubing is often used in a number of critical and rigorous applications that require that they are not susceptible to leaking or bursting open under pressure and temperature stresses. The three ASTM product standard specifications to be discussed in conjunction with copper tube testing are listed in Table 1. Each of these standards reference ASTM Standard Practice E243-97, Standard Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes

Table 1: Copper and Copper-Alloy Tube Standards.

B88-96	Standard Specification for Seamless Copper Water Pipe
B359-98:	Standard Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes With Integral Fins
B395-95:	Standard Specification for U-Bend Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes

E243 describes the procedures to be used when conducting eddy current encircling coil examination of copper and copper-alloy tubes for detecting discontinuities that are likely to cause failure of the tube. The procedures are applicable for tubes with outside diameters to 31/8 inches (79.4 mm) and wall thicknesses from 0.017 inch (0.432 mm) to 0.120 inches (3.04 mm) or as otherwise stated in ASTM product specifications or by other users of the practice.

Eddy-current testing systems used to perform inspections under the guidelines of E243 are normally installed in one of two locations:

For in-process inspection the test coil is installed directly in the processing line. Examples of in-process installations include testing in the tube welding line (for welded tubing) or in the level winding process. After inspection tubing can be in the form of individual cut to length pieces or coiled spools of tubing. Cut to length pieces can be automatically sorted into accept and reject classes. In both cases automatic paint marking systems can be used to mark the location of indications that exceed the established reject limit.

For off-line inspection the test coil is installed in an off-line inspection process. In this case the tubes are normally individual cut to length pieces that are passed through the coil sequentially and then automatically sorted and/or paint marked.

Reference standards containing artificial discontinuities are used to adjust the sensitivity setting of the eddy-current system. The reference standards are prepared to include through wall drill holes and O.D. and/or I.D. notches sized in accordance with the purchaser's requirement. The reference standard is passed through the test coil under the normal dynamic conditions of the eddy current test. The instrument parameters are adjusted to obtain a clear reject indication from each of the defects in the reference standard with particular attention paid to optimizing the signal to noise ratio. Optimization of the signal to noise ratio helps to minimize the occurrence of false indications (and therefore false rejections) caused by non-relevant discontinuities in the test material.

The inspection system parameters can be adjusted by using either a cut to length reference standard or by introducing relevant reference defects into a section of the test material prior to passing it through the test coil. Test system standardization normally has to consider the testing speed of the reference test as compared to the actual production testing speed. Instrument parameters that are critical to ensuring an acceptable test result include:

- Test frequency
- Sensitivity (gain)
- High pass and low pass filter settings
- Reject threshold settings
- Phase (only when phase dependent evaluation is used)

When testing products using the eddy-current encircling coil technique concentric mechanical centering of the test material inside the test coil is essential to ensure equal sensitivity to discontinuities around the circumference of the tube. Artificial defects can be located at 120 degree intervals around the circumference of the reference standard to ensure that the system has equal sensitivity independent of the circumferential position of the discontinuity.

When inspecting cut to length pieces the inspection system should compensate for "end effect", the large indications that are generated when the front and back ends of the test pieces pass through the test coil. Modern instrumentation normally includes the function of end suppression to blank out these undesirable signals. As the result of end suppression, a small section of the ends of the test pieces are not inspected.

Off-line testing systems normally drive the test pieces through the test coil at a constant throughput speed. Certain manufacturing processes (for example, welding lines and level winders) can generate a variation in throughput speed over the length of the test piece. When variation in throughput speed is expected an automatic speed-matching filter can be used to adjust the filter settings according to the changing speed. The automatic speed-matching filter requires the use of an encoder to measure the speed of the product. A function in the test electronics uses the measured speed to adjust the filter setting. This technique helps to better optimize the test and can result in significantly fewer non-relevant indications.

Rotating probe type eddy current systems can be used for highly sensitive O.D. surface inspection of copper tubing. The rotating probe systems offer increased sensitivity to longitudinal defects (sometimes referred to as "zippers") in the tubing. Systems with probe rotational rates up to 18,000 RPM are available, but due to the high throughput speed of level winding machines (up to 1,800 feet per minute), an encircling coil system is often used in tandem to ensure 100% surface inspection.

3 Steel pipe and tubing

Ferro-magnetic steel pipe and tubing is often utilized for a variety of applications that require that the strength, structural integrity, and mechanical properties of the material be sound. Electromagnetic nondestructive testing has long been an accepted method for inspecting these materials for surface defects and, in the case of welded materials, weld defects.

ASTM Standard Specification A513-98 describes the requirements for Electric-Resistance-Welded (ERW) Carbon and Alloy Steel Mechanical Tubing. This specification is applicable to round, square, rectangular, and special shape tubing from ½ inch (12.7 mm) to 15 inches (381.0 mm) O.D. with wall thicknesses from 0.065 inch (1.65mm) to 0.650 inch (16.50 mm) for tubing produced from hot-rolled steel and 3/8 inch (9.52 mm) to 12.0 inch (304.8 mm) O.D. with wall thicknesses from 0.022 inch (0.71 mm) to 0.134 inch (3.40 mm) for tubing produced from cold-rolled steel.

ASTM A513-98 makes reference to ASTM Standard Practices E309-95, Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation and E570-97, Flux Leakage Examination of Ferromagnetic Steel Tubular Products.

E309-95 is specifically applicable to eddy-current examination methods using an encircling coil assembly, however it also mentions that fixed or rotating probe coil assemblies may also be used to enhance the discontinuity sensitivity on larger products. As is normally the case, the interpretation and applicability of this standard practice is specified as per the contractual agreement between the supplier and the purchaser of the products.

A common technique for eddy current examination of round steel tubing and pipes is the encircling coil method. Encircling type sensors are most often configured in a differential arrangement making them most sensitive to defects that are either short in the longitudinal direction or oriented in the transverse direction. An absolute type sensor can be combined with the differential channel to provide sensitivity to gross longitudinal defects (for example, open weld seams), but absolute sensors are normally not sensitive to shallow longitudinal defects like scratches and seams, especially in larger diameter product.

Since the eddy current test is sensitive to localized variations in the magnetic permeability of the test material, a direct current (D.C.) magnetic field is superimposed at the point of inspection to magnetically saturate the test material and negate the permeability effects. The D.C. magnetization is most often accomplished using an electromagnetic yoke into which the test coil is mounted.

Attempts to test without this superimposed D.C. field result in a high background noise level and therefore a poor signal to noise ratio. A poor signal to noise ratio could result in the inability to detect discontinuities of a critical size and false indications from non-relevant indications.

The magnitude of the D.C. magnetization field must be adjusted for each O.D., steel grade, and wall thickness combination using a representative reference standard containing a drill hole defect. The magnetization level is adjusted in conjunction with the other critical eddy current test parameters to obtain the maximum signal to noise ratio. Since it is possible to over saturate the material resulting in a decreased signal to noise ratio, this parameter must be carefully adjusted for each product.

The encircling coil technique inspects the entire circumference of the section of tube or pipe that is within the effective area of the test coil. The test material must be passed concentrically through the test coil to ensure equal sensitivity to discontinuities independent of their circumferential location. Due to the integrating nature of the encircling test coil, the sensitivity generally decreases as the diameter of the test material increases.

Adjustment of the test parameters is accomplished by passing a reference standard containing representative defects through the test coil, observing the responses, and adjusting the parameters to obtain a satisfactory reject indication. Often the reference standards are prepared with defects at various locations around the circumference to ensure equal sensitivity independent of the circumferential position.

Welded steel tubing and pipe are sometimes tested in the welding process using a segmental or probe type coil that is positioned to inspect the weld zone. To ensure a valid weld inspection, the sensor must be installed at a location in the process where the weld is constantly positioned within the effective area of the sensor. Specially adapted D.C. magnetization systems that focus the saturation field into the area of inspection are often used with a segmental type coil.

For installations in the welding process it is possible to introduce drill hole defects into the strip material prior to welding to ensure the system is capable of detecting defects under process conditions. It must be noted that these types of defects are sometimes geometrically distorted due to the welding, therefore basic sensitivity should be set off-line using a defect of the critical size.

In all cases material that generates signal indications during testing should be periodically evaluated to determine the magnitude and type of discontinuities that are present. By evaluating these discontinuities the manufacturer can further refine the selectivity of the testing system relative to the various types of discontinuities.

Eddy current probe coil testing can also be used to inspect steel tubing and pipe. Systems employing rotating probe devices or fixed probes with mechanics to rotate the test material can both be used. Probe coil testing is normally sensitive to longitudinal defects due to the orientation and size of the sensors and the direction of scanning. Care must be taken to ensure that the throughput speed of the material is controlled relative to the sensor size and rotation speed to ensure suitable coverage of the material’s surface. This technique can be problematic for inspecting welded products due to the inherently large signal generated when the probe passes over the weld zone.

Magnetic flux leakage testing (MFLT) can be used for highly sensitive inspection of tubes and pipes. MFLT systems couple a high-energy magnetic field (either A.C. or D.C.) into the material and use magnetic flux sensors to detect leakage fields caused by discontinuities in the material. The principle of MFLT inspection is very similar to Magnetic Particle inspection with the exception that indications are detected by sensors instead of by visual inspection or optical methods.

Direct current (D.C.) MFLT systems can be used for tube and pipe inspection to detect O.D., I.D., and internal defects. D.C. MFLT often uses both longitudinal and transverse magnetization fields to detect transverse and longitudinal discontinuities. The transverse magnetization system is used in conjunction with a rotating probe device while the longitudinal magnetization system normally employs fixed segmental type sensors.

Alternating current (A.C.) MFLT systems are normally used in conjunction with a rotating probe device to detect longitudinally oriented O.D. surface defects. These systems exhibit significantly less background noise due to surface conditions such as scale and surface roughness when compared with rotary eddy current systems. Reliable detection of shallow seams down to 0.1 mm in depth in hot rolled material is possible.

4 Austenitic pipe and tubing

Like ferro-magnetic tubing and pipe, austenitic tubing and pipe is often used in a number of critical applications that require that the materials be free of surface defects. Eddy-current testing is often used to inspect these materials to determine the presence of harmful discontinuities.

ASTM A 312-99 is the standard specification for seamless and straight-seam welded steel pipe intended for high temperature and general corrosive service. Examples of typical applications include food processing and automotive components. A 312-99 makes reference to ASTM E 426-98, Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys.

Like the standard practice for ferro-magnetic tubing (E 309-95), E 426-98 mentions the possible use of both the encircling and probe coil techniques for inspection of the products. Most of the basic definitions for the configuration, adjustment, and standardization of the eddy current systems are similar between E 426-98 and E 309-95. The main difference is that the non-magnetic grades of austenitic pipe (for example the 300 series) generally do not require D.C. saturation magnetization for testing. Magnetic grades (for example the 400 series) will still require saturation magnetization, however smaller diameters might be suitably magnetized using a permanent magnet yoke as opposed to an electromagnet.

As-welded tubing will often require D.C. magnetization for eddy current testing due to the delta ferrite formed in the heat effected zone during welding. As in all other nondestructive tests, the best way to determine the required configuration and parameters of the testing system is to perform an applications study using representative test samples.

5 Summary and Conclusions

Electromagnetic testing is used in a number of tubing and pipe applications for determining the presence of discontinuities in both in-process and finished products. International standards (such as the ASTM Standard Specifications and Standard Practices) present guidelines for electromagnetic examination of various products. Most standards define the methodology to be used for configuring, adjusting, and standardizing the inspection systems. Contractual agreements between the manufacturers and the consumers of the products define the required specification for supply. In practice, electromagnetic testing systems can often be used to ensure that the surface defect specifications of the contracts are met.