Advanced NDE for Pipes and Tubes as per API Specifications

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Abstract
As power generation and oil and gas transmission capabilities expand to meet growing market demands worldwide, higher quality standards are being applied to the production of steel tubes and pipes. American Petroleum Institute standards such as API 5CT specify that certain grades of pipe must be inspected ultrasonically for ID and OD notches in addition to full body OD inspection using flux leakage (FLX), eddy current (EC) or magnetic particle tests for both longitudinal and transverse notches. This paper discusses recent advancements in Flux Leakage Inspection and Ultrasonic (UT) Rotary systems, offered by Magnetic Analysis Corporation, for inspection of production tubes for longitudinal, transverse and oblique defects as well as for wall thickness measurement. The introduction of rotary transverse testers removes the requirement for one set of form-fitting sensors for each material size, thus drastically reducing the cost of the transverse testing station. Newer designs provide increasingly larger sized multi-channel ultrasonic rotary systems that make testing flaws and measuring wall thickness in the same system a reality. Actual testing systems comprised of multiple testing stations including Transverse FLX, Longitudinal FLX and UT Rotary will be discussed along with testing results on recent installation demonstrating the complete inspection capability of such a system for ID, OD longitudinal, transverse, oblique notches as well as accurate full body measurement of pipe wall thickness.

1. Introduction

Steel tube and pipe producers use a wide variety of methods to evaluate and inspect their product to meet various quality standards. Such method include magnetic flux leakage (MFL) for ID and OD flaws, eddy current (EC) for OD and light wall ID flaws, and ultrasonics (UT) for wall thickness measurement and lamination defect detection or OD and ID flaw inspection. Combinations of these procedures constitute an overall quality assurance program of the OCTG producers. For certain grades, API 5CT actually mandates dual inspections using UT for ID and OD, and FLX or EC or magnetic particle for OD inspection.

This paper discusses recent developments in the flux leakage testing systems and ultrasonic rotary system from Magnetic Analysis Corporation (MAC) for inspection of steel pipes and tubes per American Petroleum Institute (API) standards.

2. Flux Leakage Principles

MFL starts with a magnet or electromagnet. The magnetic field distribution is governed by Maxwell’s equation and modern numerical modeling can accurately and visually display the flux lines representing the strength and direction of the magnetic field. A large number of flux lines represent a strong magnetic field.

When a magnet is placed next to a metal piece such as a pipe wall, most of the flux lines pass through the pipe wall as the steel pipe has much higher permeability which creates a preferred path for the flux. While most of the flux lines concentrate in the pipe wall, a few pass through the surrounding media. The lines that do not pass through the pipe wall are referred to as stray field or the air-coupled field.

Flux leakage at a metal-loss region is caused by a local decrease in the thickness of the pipe wall. At a metal-loss region, the flux carried by the thin section is less than that carried in the full wall. Flux leaks from both inner and outer surfaces of the pipe. Modeling indicates that only a nearly saturated field will result in a meaningful leakage field from the other side of the metal loss.

A sensor positioned on the outside (magnetization side) of the pipe is typically used to detect the magnetic field (Hall sensor), or the changes of the field (coil) adjacent to the pipe wall. At a metal-loss region, the sensor detects a sudden change in the flux density or magnetic field, which indicates the presence of an anomaly. In this manner, an MFL tool detects an anomaly that causes flux to leak. The detected leakage field depends on the depth, length, width, and shape of the anomaly, as well as the magnetic properties of the nearby material.

Typically, the leakage field depends on the orientation of the anomaly or defect. For longitudinally oriented defects, the magnetic field should be in the transverse direction and rotates around the pipe wall, covering the entire pipe as it travels through the tester. We call this a longitudinal flux leakage rotary, or LFX Rotoflux®. For transversely oriented defects, the pipe should be magnetized longitudinally. Coupled with rotating probes, MAC introduced the first transverse flux leakage rotary, or TFX Rotoflux®.

3. UT Inspection Principles

Ultrasound application in Nondestructive Testing (NDT) is based on detecting or monitoring echoes from a particular type of objects, mostly, top and bottom surfaces, anomalies in the wall and at both surfaces. There are two types and waves used in a typical UT detection system, longitudinal
The longitudinal wave is used for thickness measurement and lamination defect detection, while the shear wave is used for the ID and OD surface defect detection. Thickness measurement is based on accurately measuring the time of flight in certain pulse or echoes. Defect detection is more of looking for the existence of the echo in predefined time periods or gates.

The cross section of a tube is shown on Fig. 1. The right hand side of the drawing shows the detection of a crack on the inside diameter and the tube. A similar arrangement on the left side shows the geometry of flaw detection on the outside surface of the tube. The sheer wave can bounce several times between the ID and OD surfaces of the tube and any internal flaws in the path of the beam are detected as well. Notice that the right hand transducer produces a sheer wave that travels clockwise inside the tube, while the left hand transducer produces a sheer wave traveling counter clockwise. To assure the most reliable flaw detection both CW and CCW arrangements are used simultaneously. In order to generate a sheer wave the transducer is positioned with an offset. The right amount of offset depends on the sound velocity in the material of the tube and the sound velocity in the water. The required offset can be calculated using a simple formula or read from a table as a function of tube diameter and material of the tube. With this arrangement we can detect longitudinal cracks. In order to detect transverse cracks the transducer has to be located over the center of the tube and angled in a plane containing the centerline of the tube as shown on Fig. 2.

We can scan the full circumference of the tube if we rotate it around the center. However, fast rotation of long and heavy tubes is difficult to accomplish. The same result can be obtained if the set of transducers is rotated around the tube. Now, if the tube is moved along the centerline, a full body testing is achieved.

4. Advancement on LFX Rotoflux®

The recently introduced 6LFX consists of fully multiplexed 24 channel electronics with individual probe gain adjustment. Probe signals are fully amplified before multiplexing for signal transfer across the rotating headplate. Two arrays of 12 probe elements are mounted on retractable arms which can either air ride or surface ride. The arm movement also allows for testing pipes with upset ends. Each array covers 150mm. The largest rotary can run at 350 RPM, allowing 100% coverage for up to 1.5m/s production speed. This rotary can test pipe diameter from 60mm to 400mm.

All probe signals are digitized and displayed. Each probe signal is individually filtered with an IIR digital filter with the choice of manual or automatic adjustment based on the material size and rotational speed. ID and OD separations are achieved based on the flaw signal frequency disparity between the defects originated from those two surfaces. Typically, ID defects produce a lower frequency signal in comparison to the same size of OD defects. Using independent sensitivity, filter and threshold adjustments, it is possible to alarm and mark ID and OD defects separately. With built-in end suppression, the system can test within 150mm to 200mm from both front and back ends depending on the straightness of the pipe.

Instead of a strip chart recorder, the 6LFX system is equipped with full digital recording capability for storing all the pieces tested, as shown in Fig. 3. The chart simultaneously records both ID (yellow) and OD (white) indications. The recording shows the indication from a 5% ID notch along with a 20° oblique notch at 10% depth. The oblique notch is detected at considerably lower signal level than the same depth longitudinal notch. At a 20 degree angle, the OD oblique notch signal is attenuated to about half of the amplitude from the longitudinal one. The smaller the oblique angle, the less is the signal attenuation.

5. Transverse Rotary System

Traditional design of transverse testers requires a full set of probes and pole pieces for each size. The probe arrays are distributed around the entire circumference in between the pole pieces shaped into the right radius for equal sensitivity. To reduce the cost and the complexity of system
size change over, a rotating probe system coupled with a fixed longitudinal magnetization structure is considered. In this configuration, only one complete set of probe arrays are needed for the entire size range.

Figure 4 shows the detector (probe) assembly as a defect approaches the spinning probes. The detector assembly is spinning around the pipe as the pipe is moving through the system in the direction indicated.

As the pipe moves, the detector assembly also moves providing a spiral path or helical pitch. The helical pitch from all the probe or detector elements should provide complete coverage of the pipe surface as it passes through the rotary tester, in similar fashion to the longitudinal tester.

As the pipe movement brings the flaw to the probe assembly at least one of the detector elements on one of the assemblies will cross the flaw in the direction of pipe movement, generating a flaw signal from the flux leakage, as shown in Fig.5. The number of probe elements in each array, the number of arrays needed, element size and spacing are based on the testing standard and size requirement. Some basic calculations confirm that there are some very specific relationships among notch length, detector length and width, the probe rotational speed and the material traveling speed. The main design considerations are the coverage and sensitivity or minimum flaw detectability.

Based on the analysis of coverage and our experience with the probe sensing elements, the optimum system design was determined to contain 48 or 96 channels and probes for the maximum size of 400mm diameter pipe depending on the notch length requirement of 50mm or 25mm. For systems testing a maximum size of 200mm diameter, a 48 channel system can test for 25mm notches. Since the probe number does not change for the entire testing range, the largest size is always the most difficult to achieve full coverage.

To limit the untested end, these probe elements are packed into 4 arrays mounted on the movable arms. Each probe arm can be programmed to retract for the pipe end when surface riding or for the upset end, as in the case for LFX. The electromagnet structure is somewhat larger to allow for the spinning probes and supporting mechanics fit in between the poles. A similar multiplexing technique to the LFX is used in this system. To ensure the correct coverage,
the rotary speed is programmed to vary according to the pipe traveling speed, as outlined in the constraint equations.

The tester is capable of detecting a 5% ID transverse notches on good quality tubes as shown in Fig. 6 which is a recording of a 60mm diameter x 5.5mm wall sample on a 300mm system during check out prior to installation in the customer’s plant. Beside the indicated defects, the other indications are the welds introduced when making the sample defects. The sample was cut into 4 pieces and welded back together after the reference defects were put in. The front end was not fully tested because the mechanics needed for transporting the pipe into the tester were not available during this check out. In this figure, the 5% notch is clearly visible, however, testing to a 5% level during normal production in a mill environment may result in a high level of rejected material. Only the highest quality pipes can test for 5% ID notch standard during production.

6. Advancement on UT Rotary

Recent introductions of many size and channel UT rotaries greatly improved the feasibility of UT rotary application for steel tube and pipe inspections, including wall thickness measurement, OD and ID dimensional measurement, OD and ID longitudinal, transverse and oblique flaw detection. A typical setup for longitudinal or transverse notch can detect defects oriented within +/- 5 degrees of the intended direction. The other orientations are not detectable with those setups. Existing UT rotaries are mostly aimed to detecting notches in these two main orientations, longitudinal and transverse, and they are meeting most of the standards. Newer requirements are emerging which include oblique notches oriented other than the longitudinal or transverse directions. This is modeled with notches oriented at 25-45 degrees to either the main directions.

To detect an oblique notch with known orientations, a combination of typical transverse notch detection transducer, which is cylindrically focused with the center line of the beam at 19 degrees to the center line of the transducer housing, and horizontal offset typically used for longitudinal flaw detection, as shown in Fig. 7.
In the ECHOMAC ROTARY TESTER up to 16 transducers are mounted in a rotating chamber. The electrical connections are made through rotary capacitors or rotary transformers. The tube is moved through the center of the rotor and the space between the transducers and the tube is filled with water. The rotational speed is between 1800 and 4000 RPM depending on the size range, allowing a testing speed of up to 400 feet per minute.

To achieve full-volume testing, the minimum number of transducers in a rotary would include one (1) for the thickness and lamination defects, two (2) for longitudinal notches (clockwise and counter-clockwise), two (2) for transverse notches (forward and reverse), two (2) for oblique notches (clockwise and counter clockwise). Higher production speed might need to multiply the number of channels for coverage.

Figure 8 shows a typical recording of a 16 channel UT rotary testing 139mm x 7.72mm standard. The thickness channels (1 and 2) pick up all three welds and a complete ID wall reduction. The lamination channels (15 and 16) detects all those plus localized wall loss. Lamination detection shares transducers with the thickness channels but use separate processing electronics. This standard also contains 5% and 10% ID and OD longitudinal, transverse and oblique (38 to 45 degrees) notches are detected separately with channels dedicated for longitudinal (3-6), transverse (7-10) and oblique (11-14) notches. The longitudinal and transverse channels are also detection the defects placed near the ends.
7. Total Quality Program

A typical quality testing system for a steel pipe/tube production line includes a transverse FLX testing station, longitudinal FLX testing station and ultrasonic wall thickness measurement, lamination defects, ID and OD dimensional (ID and OD) measurement, transverse and oblique notches detection station, testing to API 5CT standard, as well as a demagnetization station. Even though claims have been emerging about thickness measurement using flux leakage techniques, our experience seems to indicate that UT is the only reliable approach to accurately measure the pipe wall thickness and, if necessary, dimensional (ID and OD) measurement. Flux leakage or flux density measurement cannot distinguish the resulting flux changes from air gap variation, from material property variation or from thickness variation. It’s more of a monitoring tool for changes or anomalies in the pipe. Figure 9 shows a transverse Rotoflux®, a longitudinal Rotoflux®, a Demag and a UT rotary together for a seamless pipe manufacturing production line.

Conclusions

Multiple principle and testing stations are essential to quality assurance programs for steel tube and pipe producers. Recent advancements on UT and FLX rotaries provide an array of choices for effective and economic testing of steel pipe and tubes.

References