NON-DESTRUCTIVE TESTING OF DUPLEX STAINLESS STEEL

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Abstract

This paper will discuss the selection of inspection methods for testing Super Duplex stainless product for the off shore energy exploration, petrochemical, food & beverage, and power generation industry. We will show how Eddy Current and Ultrasonics will meet requirements set up by ASTM, and EN standards in regards to Super Duplex stainless steel.

The Non Destructive Testing (NDT) methods used for inspection of Super Duplex stainless steel products are Radiography, Eddy Current and Ultrasonics.

Eddy Current – used to find surface discontinuities such as pits, weld defects, inclusions and Sigma Phase variations.

Ultrasonics – used to find laminations, wall thickness variations, and discontinuities on the OD and ID such as pits, cracks, and weld defects.

Radiography – used to inspect orbital welds, strip splices and offline verification of other NDT methods.

Super Duplex stainless steels have been around for 80+ years[1]. Newer Super Duplex alloys are characterized by higher strength and better stress corrosion cracking resistance than most austenitic alloys. This has increased the need for more stringent eddy current testing. This increase is particularly found in the onshore and offshore oil and gas industry, chemical processing, heat exchangers for power generation, desalination equipment, and wastewater treatment facilities.

Eddy Current testing is one of the most widely used NDT Inspection method for metal tubular products. It is relatively easy to use, works within a wide range of production speeds, and has a relatively low cost of operation. However, Duplex and Super-duplex Stainless Steel tubes by definition contain about 50% ferrite in their microstructure which results in permeability variations within the grain boundaries of the microstructure of the Duplex Stainless product. These permeability variations present a problem for eddy current testing in that they act to shield or prevent the penetration of the eddy current field from sufficiently entering the metal and thereby yield poor test results[2].

The use of an Eddy Current encircling coil coupled with a saturation coil suppresses the effects of permeability variations which appear as “noise” within the test results.

Another use of Eddy Current is to identify Sigma Phase variations. Sigma phase is an iron-chromium (roughly 50-50) phase that can form from ferrite in austenitic stainless steel weld metal at elevated temperatures (approximately between 450°C and 850°C some believe it goes to 1050°C) [3]. It therefore forms during high temperature service

and its presence in the stainless steel is only apparent at room temperature, during plant shutdown, the stigmatized material becomes extremely brittle and will crack readily with low toughness[4].

Multiple Channel Rotary Ultrasonic Immersion testing is used for detection of discontinuities as well as wall thickness variations. The use of high speed rotaries enables the testing to keep up with production output.

INTRODUCTION

The quality of tubular Super Duplex stainless steel products from manufacturers worldwide can have serious problems that affect the end use of the product, despite having detailed manufacturing specifications based on existing standards.

The use of Super Duplex stainless steel components that do not meet the purchaser's specified requirements can have serious consequences. When discovered in the supply chain or during fabrication, poor quality duplex materials can lead to significant project delays. However, once in service, failures can be substantially more serious, potentially leading to environmental and personnel safety issues and significant business loss[6].

Non Destructive Testing (NDT) is used to improve and enhance quality control programs. The selection of all applicable NDT methods is vital in finding discontinuities and meeting standard requirements of ASTM and EN.

RADIOGRAPHY

X-RAY examination of strip splice and orbital welds has been performed using film-based and digital radiographic techniques in accordance with ASME Section V [ref. 7]. Examination of strip splice welds is performed after they have been formed into a tubular shape, welded and heat-treated. Examination of the orbital welds is performed after local post weld heat treatment[2]. Radiography is also used as additional verification of other indications found by Ultrasonic and Eddy Current methods.

EDDY CURRENT

Welded stainless steel products can present a special problem in eddy-current examination. The weld area can usually be distinguished from the parent metal if the tubing has received little or no working after welding. This occurs when the as-welded structure contains delta ferrite which is magnetic and can cause a high-background noise level or spurious indications, or both. If drawn after welding, these effects may be reduced so that welded tubing cannot be distinguished from seamless tubing. These effects do not necessarily preclude the eddy current examination of as-welded tubing; however, the examination apparatus will probably require different adjustments for materials with as-welded and wrought structures. Thus, the minimum size discontinuity that can be detected may also be different (ASTM E426-98).

The key to successfully applying eddy current techniques is to suppress the permeability variations by magnetically saturating the test material using an external source. Saturation is defined as the degree of magnetization produced in a ferromagnetic material for which the incremental permeability has decreased substantially to unity. Without magnetic saturation, permeability variations show up as what we will be frequently referring to as “noise” in this paper. The end goal is to minimize this noise in order to optimize the signal-to-noise (S/N) ratio, the signal being the magnitude of the response of the test instrument to the degree of defect we establish as our rejection threshold.

Eddy Current Reference Standards

E426 Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys

In preparing a reference standard for welded tubing, artificial discontinuities should be placed in both the weld metal and the parent metal if both are to be examined. The apparatus is then adjusted to obtain an optimum signal-to-noise ratio. Notches should be produced by Electric Discharge Machining (EDM). Milled notches, which are mechanically produced, tend to cold work the surface of the product, which affects the Eddy Current response. The variations in dimensions of a notch, which has width, length and depth, each can affect the Eddy Current signal differently. The final notch dimensions are subject to agreement between the customer and manufacturer.

E309 Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation

According to ASTM Standard E309, Longitudinal notch depth is usually specified as a percentage of nominal wall thickness and values of 10%, 12 1/2%, or 20 % are typical. The width of a longitudinal notch for eddy-current examination should be specified. A narrower notch is more difficult to detect than a wider notch. Maximum notch lengths of 1/4”, 1/2”, and 1.0” are most typical. Because the Eddy Current coil is “seeing” the volume of missing material (artificial defect) under the coil winding, the shorter notch can be more difficult to detect.

This specification also references Transverse notches. Depth is measured at the deepest point and is usually specified as a percentage of nominal wall thickness. Values of 10%, 12 1/2%, and 20 % are typical. The width of the transverse notches shall be the minimum practical but not more than 1/16 in.

Drilled through holes are used for standardization and they are relatively easy to detect. Typical drilled hole diameters range from 20% to 50 % of the nominal tube wall thickness. Traditionally a 1/32 or a 1/16” diameter hole is specified for use with all sizes of tubing.

Practical Eddy Current Testing of Super Duplex Stainless Tube

In accordance with ASTM E309, saturation is achieved by increasing field strength to the point at which there is no further reduction in noise. The technique is to use a DC Saturation Coil System. These types of systems use two types of coils that we will be referring to as a DC saturation coil, and an eddy current test coil. As shown in figure 1, The DC Saturation coil encompasses a cylindrical eddy current test coil. The DC current is often supplied from a welding generator, at up to 200 amps. This Coil system must be cooled to remove the heat from power dissipation. This is done by circulating cooled water though the saturation winding which is made of copper tubing in a closed circuit with a heat exchanger similar to the radiator in an automobile. The eddy current coil is constructed with steel end bells that act as pole pieces. DC Saturation is traditionally a better and more reliable method to reduce the material permeability to unity. It will produce a much stronger magnetic field for its size than a permanent magnet coil.

FIG. 1 SCHEMATIC OF SATURATION COIL

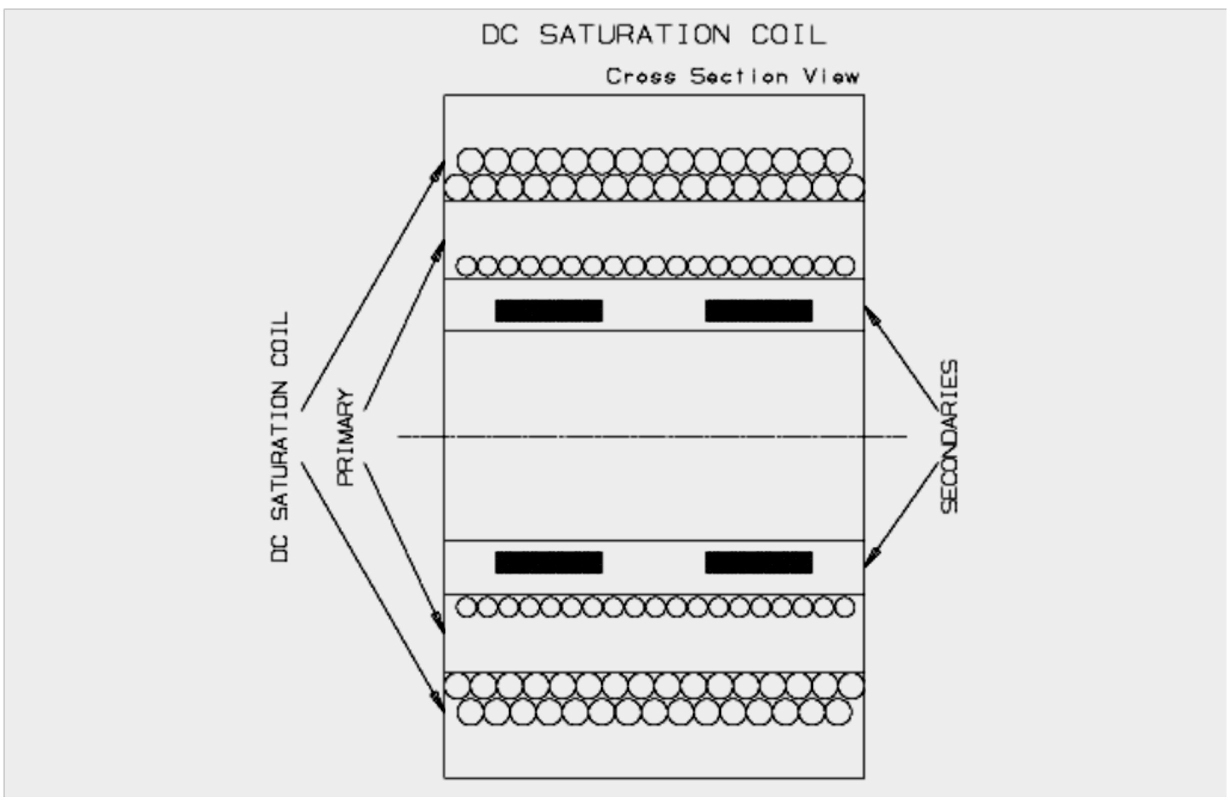

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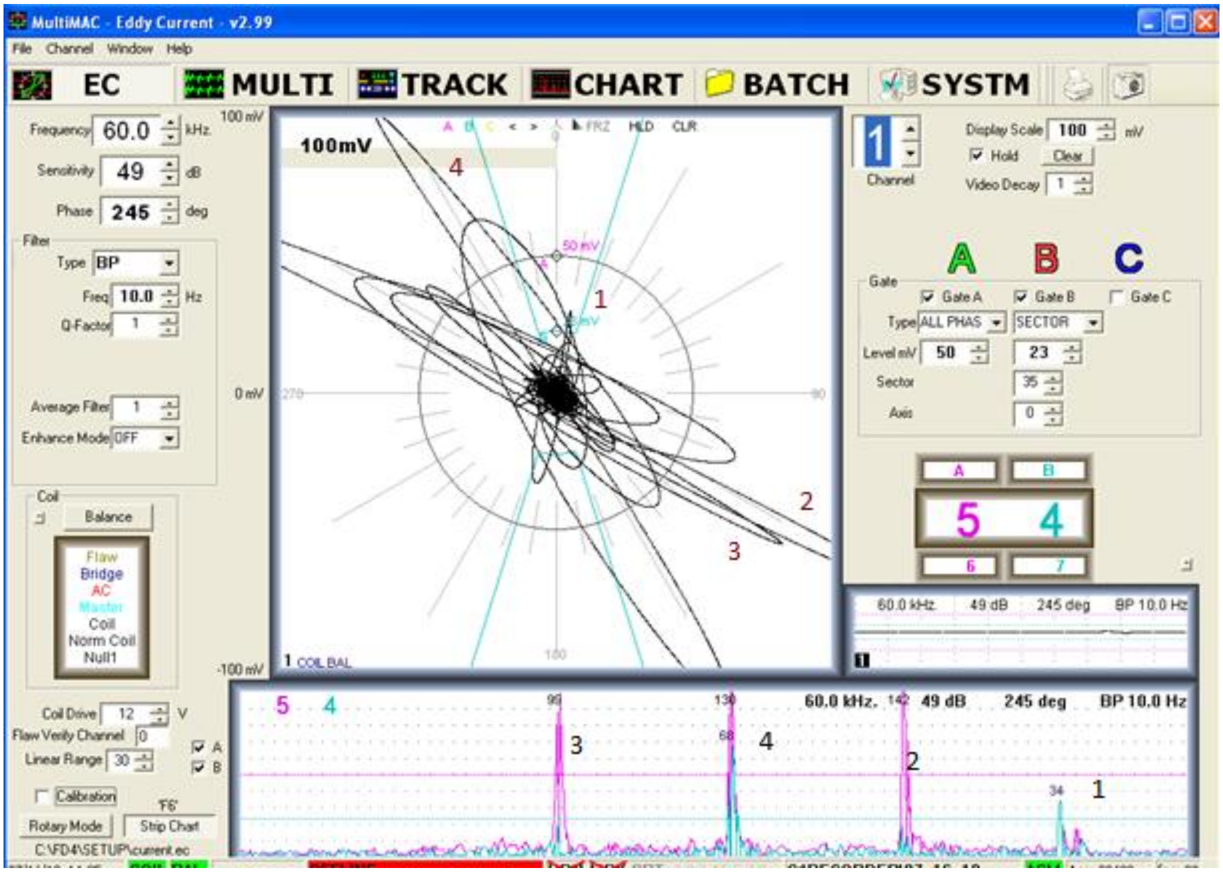
Table 1 shows specifications of a 2507 Super Duplex Stainless Steel tube used as an eddy current standard. This tube was used in performing an equipment setup calibration, the results of which are shown in figure 2. The ID notch is clearly visible on the polar plot as the smaller vertical signal. On the bottom strip chart, the signal to noise ratio can be better seen with respect to the numerically labeled defects as referenced in table 1. Eddy current settings are seen on the screen in figure 2. All settings being equal, the saturation current was lowered from 100 to 50amps in Figure 3. The ID notch is completely buried in the noise as a result of insufficient saturation.

TABLE 1- EDDY CURRENT STANDARD 2507 0.634" OD X 0.065" WALL

Defect	Type	Depth	Width	Length	Location	Orientation
1	EDM	0.0064	0.0284	0.250	ID	Transverse
2	EDM	0.0062	0.0298	0.250	OD	Transverse
3	EDM	0.0063	0.0294	0.250	OD	Longitudinal
4	Hole	Thru	0.031	0.031	ID/OD	N/A

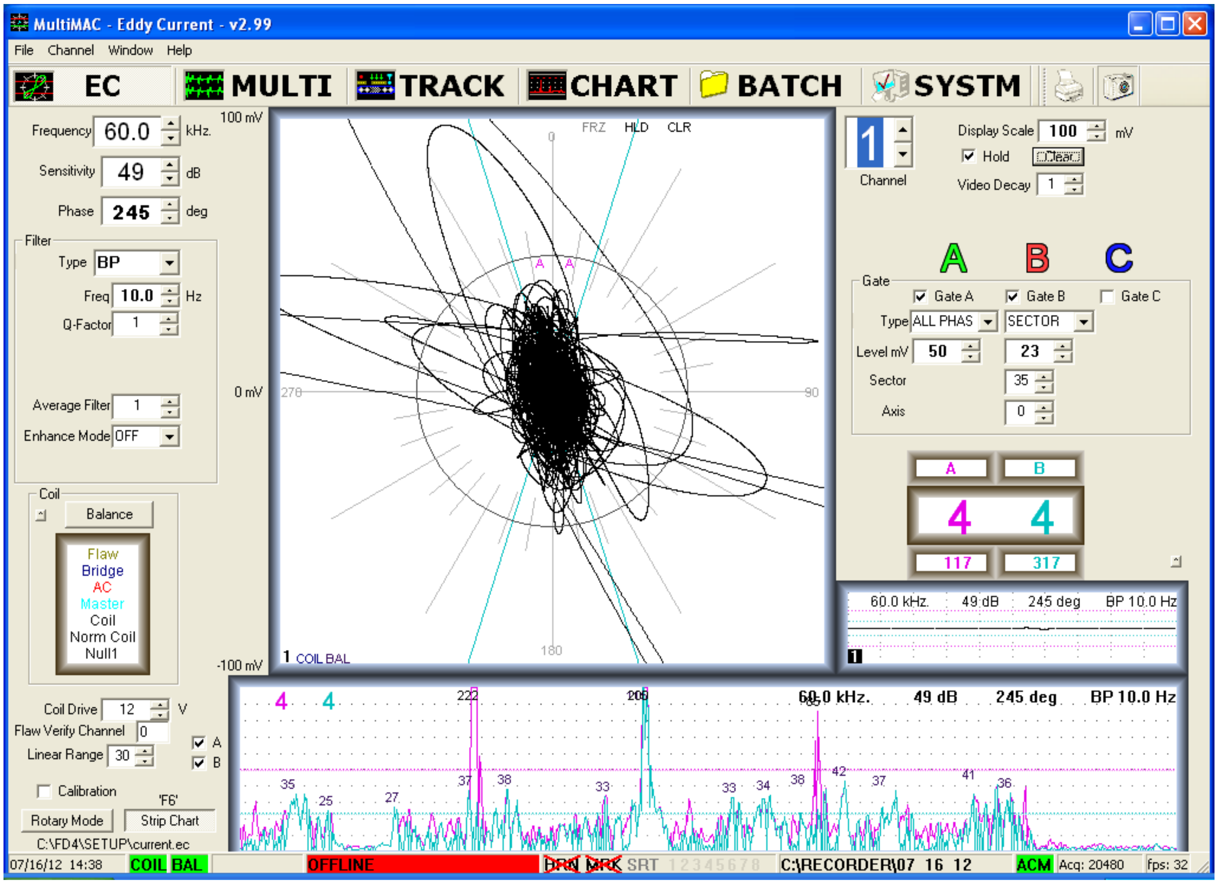
COIL XJDD-075; SPEED 20 FPM; FILL FACTOR= 71%; DC CURRENT = 100 AMPS

FIG. 2- 2507 EC STANDARD @ 100AMPS



Courtesy of RathGibson North Branch NJ

FIG. 3- 2507 EC STANDARD @50AMPS



Courtesy of RathGibson North Branch NJ

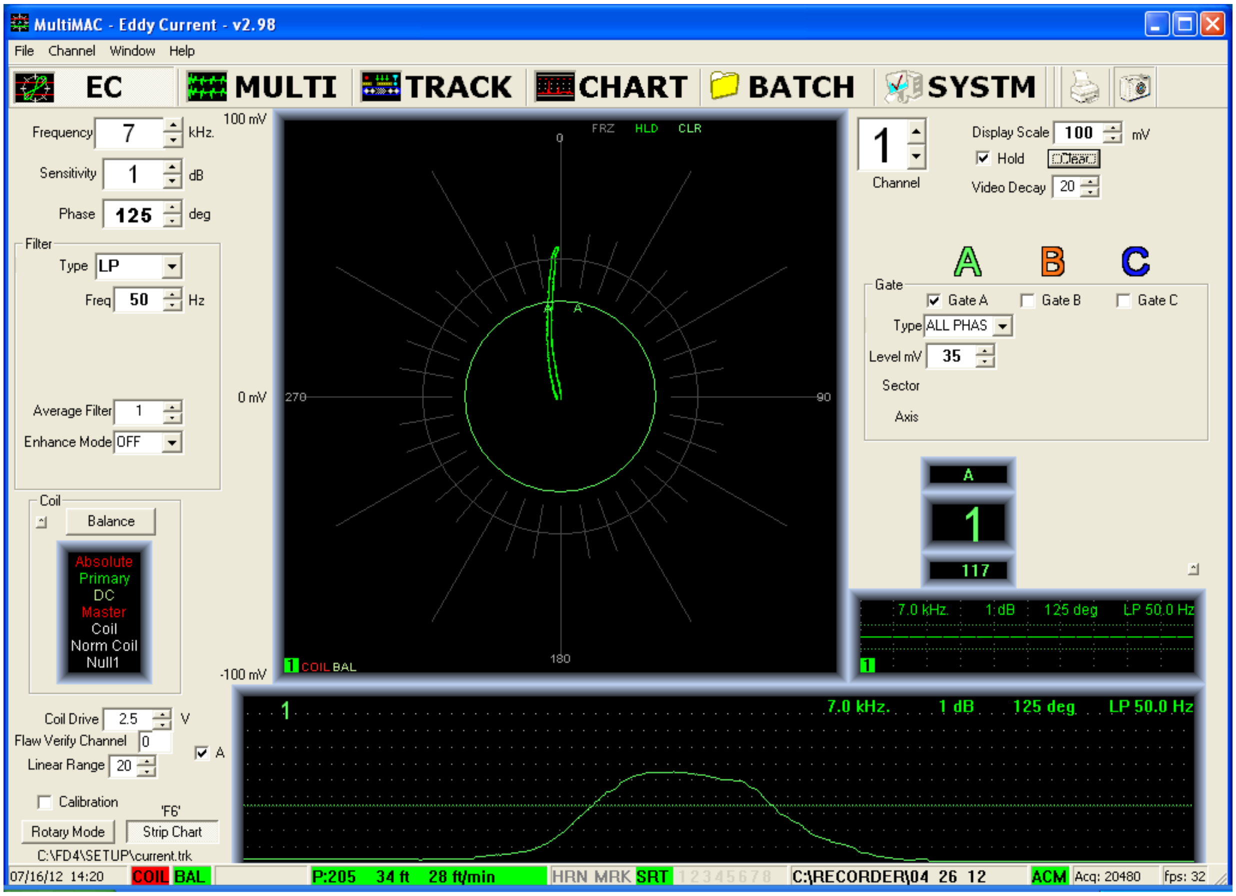
SIGMA PHASE

When manufacturing different grades of Duplex tubing, testing for Sigma Phase is a very important consideration. Currently ASTM specifications do not include control of ferrite and intermetallic phases, quite possibly due to a lack of knowledge of a suitable test method as presented here[5].

Sigma Phase is a brittle, nonmagnetic phase of tetragonal structure occurring in many transition metal alloys; frequently encountered in high chromium stainless steels. It forms predominantly out of delta-ferrite; Sigma phase is not only undesirable because of its brittle effect and poor impact strength, but also for its very low corrosion resistance. Some metallurgists believe that sigma phase commonly occurs at temperatures between 600°C and 900°C[7]. Another cause of sigma phase is due to a malfunction of the high temperature furnace; causing the material to undergo an extended length of time in heat treatment.

Testing for Sigma Phase condition is done quite easily in line and at the same time with defect testing. The test consists of a two channel Eddy Current coil tester. One channel (null) is used for the detection of typical defects, while the other channel (absolute) is used for finding sigma phase. A reference standard with known sigma phase percentage is used to calibrate the absolute test channel. The response shown in Figure 7 is from a .634” OD X .065” wall 2507 reference standard. The percentage of Sigma Phase was determined as less than 3% by metallographic examination. The response resulting from sigma phase with these settings is much greater than from other variables typically seen during an absolute eddy current test. A wide winding in the Absolute test coil tends to average localized effects not of concern such as cold working so they do not present a problem. Even significant wall thickness changes may not cause deflection outside the gated zone.

Fig. 7- 2507 Sigma Phase response (sigma <3%)



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ULTRASONICS

When internal defects, inclusions, and wall thickness need to be detected, ultrasonic inspection techniques is often the best choice. An ultrasonic rotary immersion test instrument with negative square pulsers in pulse echo mode, medium damped highly selective transducers combined with a UT rotary that uses a rotary transformer for signal coupling to the transducer, fully optimizes UT testing efficiency. A unique rotating seal-less water coupling system permit UT inspection at high throughput speeds.

Shear waves are used to detect internal longitudinal and transverse defects while compression waves can accurately measure wall thickness and lamination defects.

ULTRASONIC REFERENCE STANDARDS

In accordance with EN 10246-7 (Non-Destructive Testing of Steel Tubes) and ASTM E213 (Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing), the notch dimensions, which are length, depth, and width (and for V-notches, they include an angle) must be decided upon by the using party or parties. Reflection amplitudes from V-, square-, and U-shaped notches of comparable dimensions may vary widely depending on the angle, frequency, and vibration mode of the interrogating sound beam. The helical pitch of inspection shall be small enough to ensure 100% coverage of the tube or pipe.

TABLE 2- ULTRASONIC STANDARD 2507 0.634" OD X 0.065" WALL

Defect	Type	Depth	Width	Length	Location	Orientation
1	EDM	0.0062	0.0109	0.494	ID	Longitudinal
2	EDM	0.0063	0.0111	0.493	OD	Longitudinal

TRANSDUCER TS361CA, 10MHZ: 45° SHEAR

PRACTICAL ULTRASONIC TESTING OF SUPER DUPLEX STAINLESS TUBE

Table 2 shows specifications of a 2507 Ultrasonic standard tube. This tube was used in performing the equipment setup calibration. The transducers used are 10 MHz, 1.5" focal length with general purpose damping characteristics. Two channels of testing are used for both 45^{o} clockwise and counterclockwise shear waves. A 50mm Ultrasonic rotary rotating at 3000RPM, and achieving better than 100% test coverage at the test speed of 20fpm. Figures 4 and 5 show the A-scan of the ID and OD notch respectively, as well as the settings used for the test. Figure 6 shows a strip chart of the tube which better represents the signal to noise for both notches. The reject gate level is set at 80%, but baseline noise level can be seen below 40%.

Fig. 4- 2507 ID notch

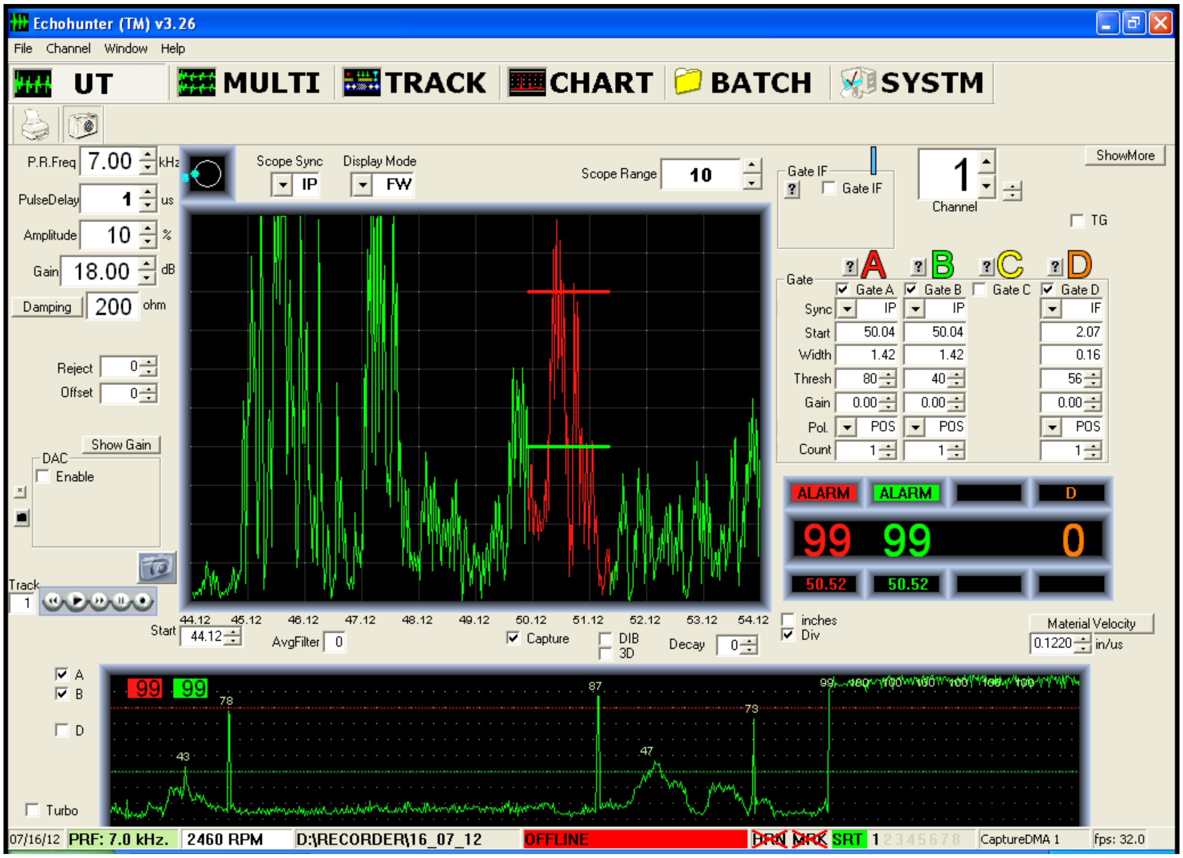

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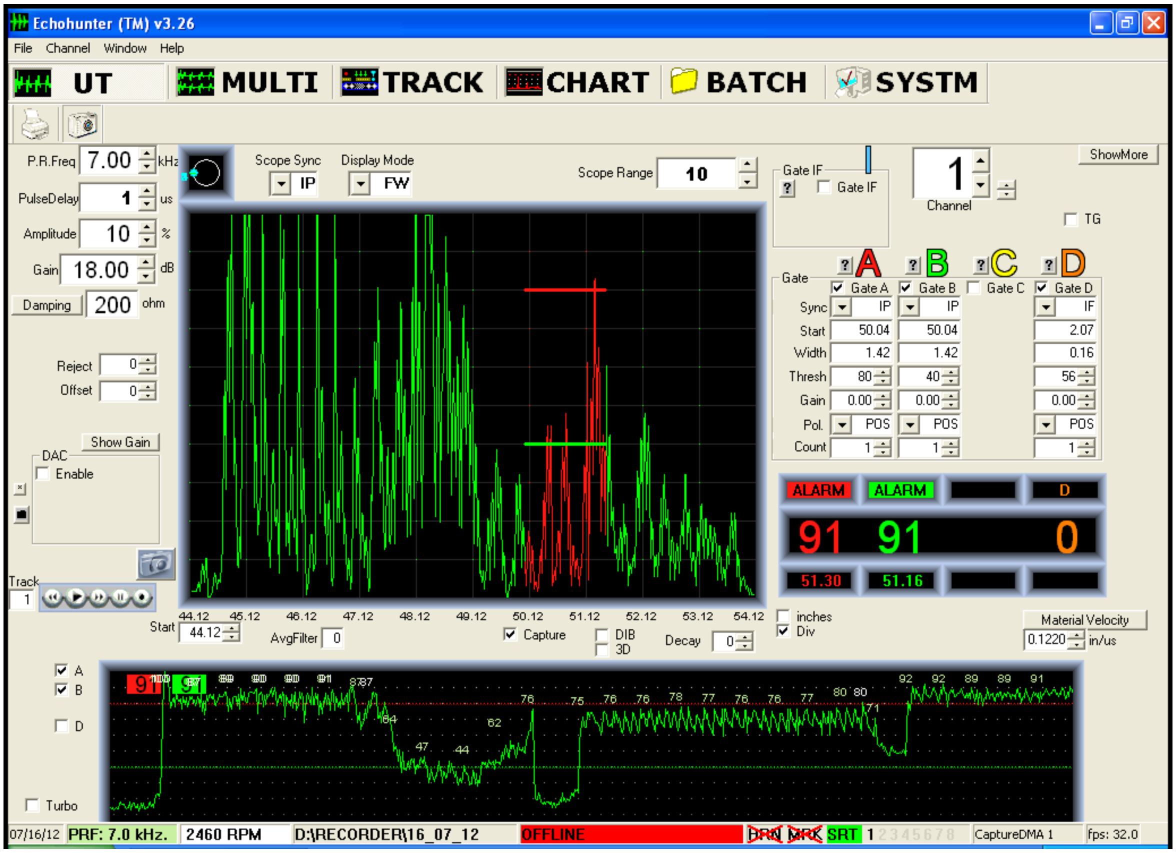
Fig. 5- 2507 OD notch



Courtesy of RathGibson North Branch NJ

Fig. 6- Strip chart of 2507 UT standard

Courtesy of RathGibson North Branch NJ

The ultrasonic rotary picked up on both ID and OD notches; with the OD notch specifications being narrower and shorter than that specified in the eddy current standards. In order to meet the demanding specifications by ASTM & EN, it will be necessary to inspect material with eddy current or ultrasonic inspection methods. The best inspection results are achieved when using a combination of both UT and ET test methods. With both test methods in place, transverse and longitudinal defects along with sigma phase and wall thickness variations may be detected.

Conclusion

While in accordance to the standards for inspecting Super Duplex Stainless Steel with UT, the detection of transverse defects may not be mandatory. However, in the standards for eddy current testing, it is mandatory; while an ID longitudinal defect is less likely to be detected.

While a DC saturated encircling eddy current test inspects the surface and subsurface for defects and an absolute coil checks for sigma phase, an ultrasonic rotary could be more quantitative in detecting ID discontinuities.

We have seen that by combining eddy current for surface transverse and longitudinal defect detections and subsurface transverse defect detections along with ultrasonics for internal longitudinal defects and wall thickness, 100% coverage can be obtained.

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