Weld Seam Inspection of Thick Wall Austenitic Steel Tubes beyond Standard Eddy Current Technology

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Abstract

The Remote Field Eddy Current Technique is a specific type of electromagnetic nondestructive testing that is increasingly being employed for the weld seam inspection of thick walled austenitic steel tube. Its main advantage is its capability of penetrating wall thickness to a far greater depth than standard eddy current testing. While this application is relatively new and there is therefore little practical experience, the field trials that have been performed are extremely promising. This paper explains the theory behind the technique and presents the results of laboratory and field trials.

Introduction

The Remote Field Eddy Current Technique (RFEC) is a specific type of electromagnetic nondestructive testing that is increasingly being employed for the weld seam inspection of thick walled austenitic steel tube. Its main advantage is its capability of penetrating wall thickness to a far greater depth than standard eddy current testing. While this application is relatively new and there is therefore little practical experience, the field trials that have been performed are extremely promising.

Principle of the Remote Field Eddy Current Technique

An RFEC probe consists of an exciter coil and a detector coil at a certain distance from each other (Figure 1). The probe is positioned over the weld seam to be inspected. A low-frequency alternating current (normally sinusoidal) flows through the exciter coil.

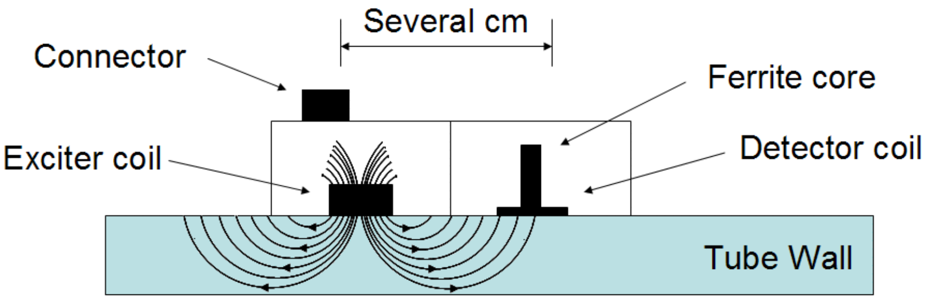


Figure 1. Principle of the remote field eddy current technique

This exciter current causes an electromagnetic field to be induced in the weld seam. The energy of the field spreads out into the tube wall. The eddy currents induced in the tube wall generate a secondary field that is much weaker than the primary field located directly at the exciter coil. The direction of energy flow is from the outside to the inside of the tube. This area is called the “near field” as shown in Figure. 2.

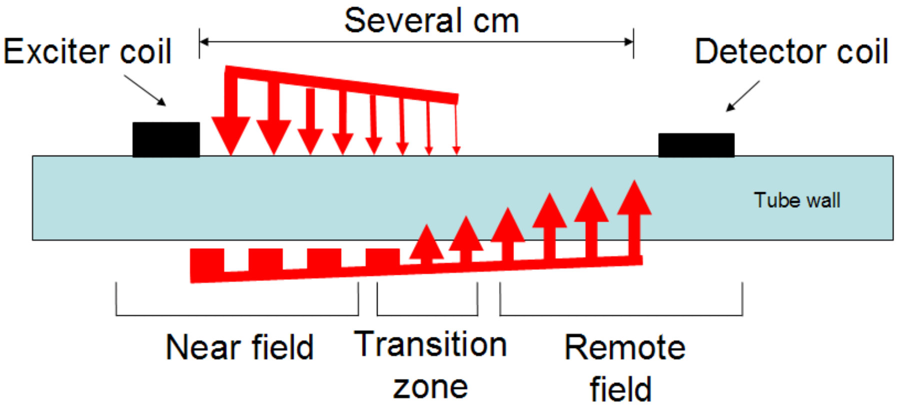


Figure 2. Interaction of near field and remote field

The near field provides the energy for the induction of eddy currents in the tube wall and therefore has a steep gradient as the distance from the exciter coil increases. Thus, at a certain distance along the tube from the exciter coil, there is an area where the secondary field is stronger than the primary field. This area is called the “remote field”.

The area between the near field and the remote field is called the “transition zone”. Here the direction of energy flow is reversed. A detector coil placed beyond this area in the remote field will measure an electromagnetic field that is induced by energy that has passed through the tube wall twice (once directly under the exciter coil through the wall and once received by the detector coil coming out the tube.) Thus, the field is generated by two different energy paths. On the direct coupling path, the energy comes directly from the exciter coil, while on the indirect coupling path, the energy passes to the inside of the tube and is transmitted back to the outside. A defect located in the tube wall in the indirect coupling path can be detected by a change in the remote field. Traditional eddy current testing only makes use of the direct coupling path, where changes in the near field indicate a defect on the surface of the material.

Penetration Depth for Different Frequencies and Materials

The penetration depth of eddy currents is the depth at which the eddy current amplitude has dropped to a value of 1/e, or 37%, of the eddy current density at the surface of the material.

The penetration depth can be analyzed in its response to the electromagnetic characteristics of the material, the testing environment and the sensor design. Thus, it is possible to determine the conditions that produce a particularly high penetration depth and the areas of application in which remote field testing is particularly beneficial.

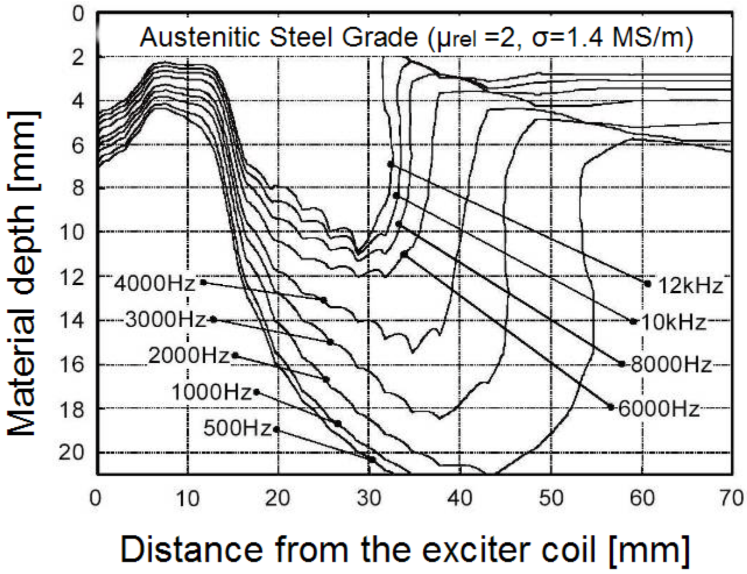


Figure 3. Penetration depth against distance from exciter coil at various frequencies for austenitic steel

Figure 3 shows penetration depths at increasing distances from the coil for various excitation frequencies between 500 Hz to 12 kHz. The penetration depth clearly decreases with increasing frequency. At the same time, the position of the maximum penetration depth shifts toward the excitation coil. Above 6000 Hz the influence of the excitation frequency on the penetration depth becomes negligible. This U-shaped curve is characteristic of the penetration depth in materials.

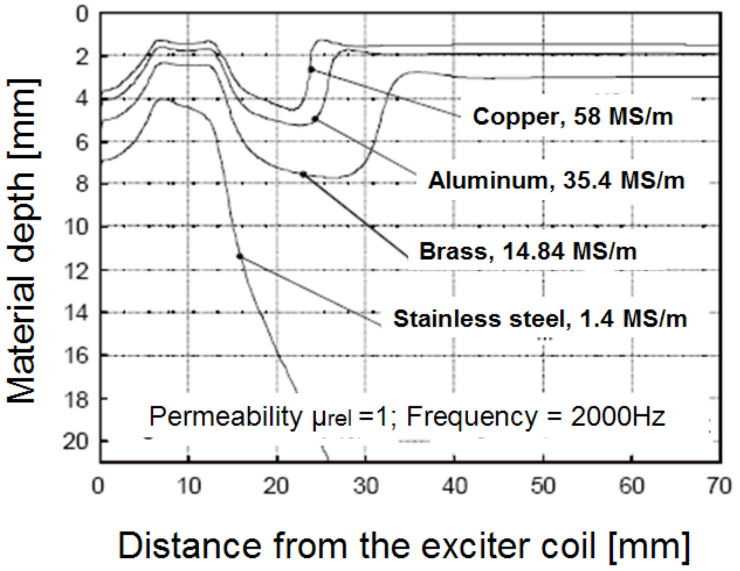


Figure 4. Penetration depth against distance from exciter coil for various metals

The electrical conductivity of austenitic materials is only slightly affected by differences in the material. Figure 4 shows penetration depths at increasing distance from the exciter coil for materials of varying electrical conductivity (copper, brass, aluminum). In agreement with Figure 3, the penetration depth reduces with increasing conductivity while the position of maximum penetration depth shifts toward the excitation coil.

Laboratory Example

The following example shows a plate with a thickness of 10 mm (material type ASTM A312, TP 316L) into which 2 internal notches and 1 drilled hole have been introduced (Figure 5). The two internal notches are intended to replicate defects found naturally on the inside of the tube. The bore hole was introduced as a control defect for field tests. In field tests, it is impossible to introduce internal notches. As a substitute, a bore hole is drilled into the weld seam and tested. In order to have a laboratory comparison, the bore hole is also introduced into the laboratory specimen. The measurements were performed with air gap of 1 mm and a frequency of 1.3 kHz.

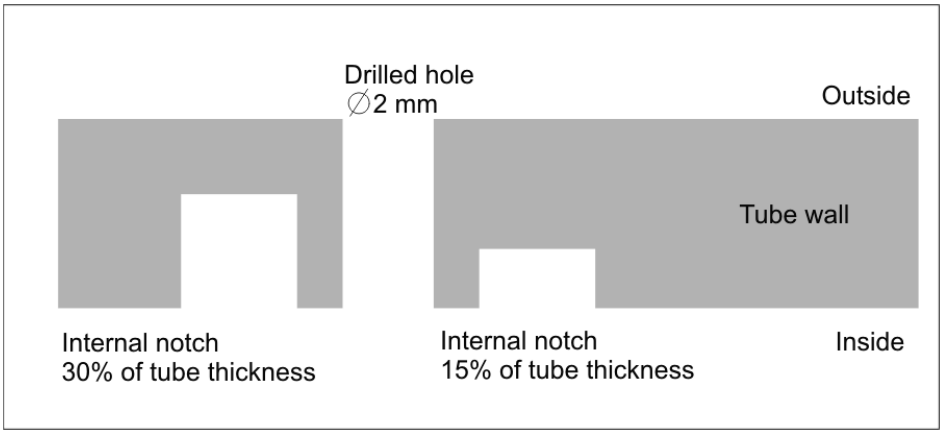


Figure 5. Tube wall with standard defects for calibration

The results of this laboratory test are shown in Figure 6. The signals clearly identify the internal notches and the bore hole. In fact, the defect signal amplitude of the smaller internal notch and the bore hole are roughly the same, a fact that will be used later in the field test to draw conclusions about the effectiveness of testing.

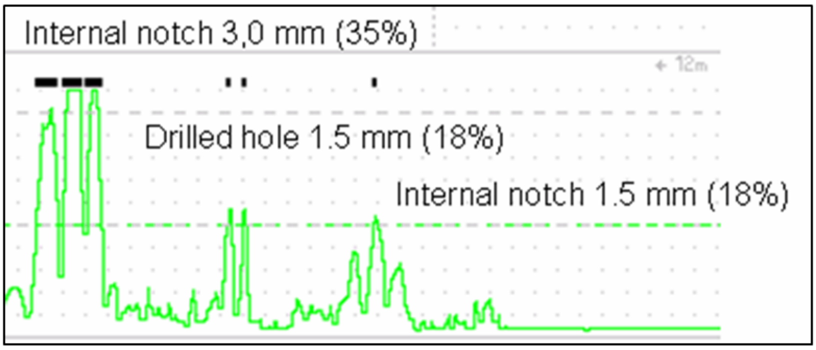
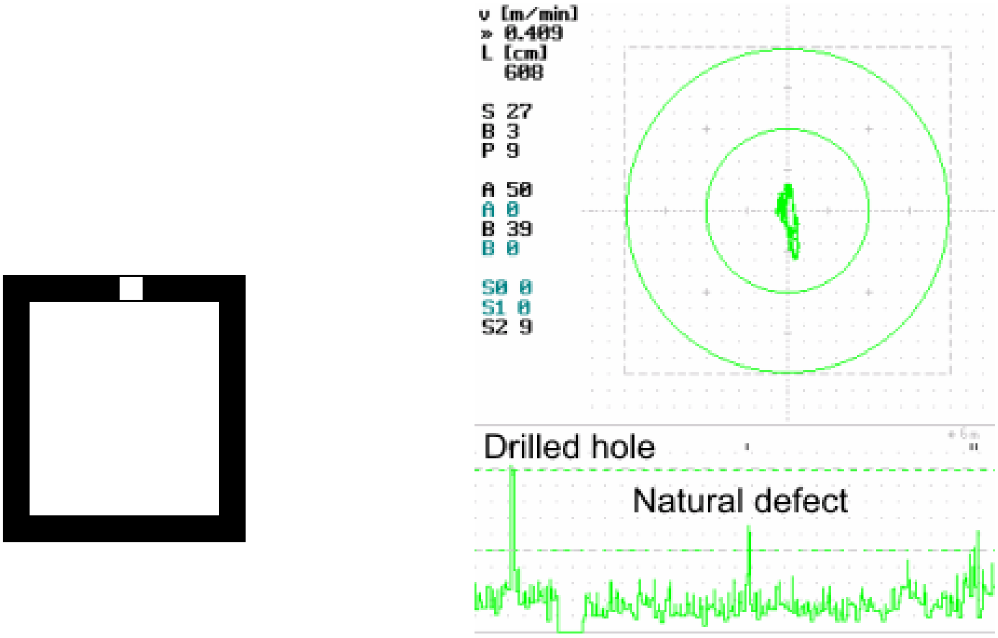


Figure 6. Signals from internal notches and drilled hole

Field Example

This example (Figure 7) shows an installation of the remote field inspection system in a welding line for square tubes of 8” x 8” x 0.375” (thickness of 9.5 mm). The manufacturer wishes to find welding defects in the weld seam. For calibration, bore holes with a diameter of 2 mm were introduced into the weld seam during production as shown in Figure 8. The signal resulting from these bore holes was easily discernable. In light of the laboratory testing results, which proved that good bore hole signals imply a good response to internal defects as well, it can be concluded that this system will also be able to readily identify internal defects.

Figure 7. Testing setup in plant for square tubes showing the eddy current tester in front of the test head and the remote field probe in the insert



Position of
2 mm drilled hole

Signal clearly identifies drilled hole and
coincidentally also finds a natural defect

Figure 8. Signals showing drilled hole and natural defect on inside of tube

In addition, the signal also reveals the existence of a natural defects on the inside of the weld seam. An example of a such a natural defect is shown in Figure 9.

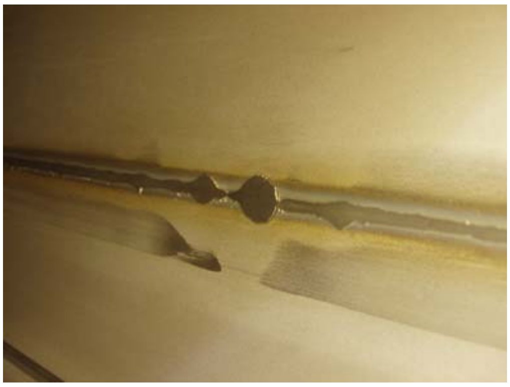


Figure 9. Natural weld seam defect on inner wall of tube

Conclusion

For many manufacturers of welded austenitic tubes, flawless quality is essential to remain competitive. Until now, finding flaws on the inner surface of tubes was costly and complicated. The only alternative was to use X-rays and borescopes to inspect the product on the inside after production. Ultrasound, the other method of choice, is not feasible in this case because of the grain structure of the weld seams.

With RFEC testing instruments, a new cost-effective method is now available. Using a special external probe, the tubes can be tested during production, any flaws are marked and the test results are documented comprehensively. Because the only other alternative for austenitic tubes is to use X-ray testing, with its exorbitant film costs and stringent safety requirements, this new method can significantly reduce production costs. With this method, the only tubes that are actually subjected to the final X-ray control are those that were sorted out by the RFEC method and then repaired.

In conclusion, the remote field eddy current technique has great potential and has is already being used successfully in industry for weld seam testing of thick-walled tube.

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