4th Middle East NDT Conference and Exhibition, Kingdom of Bahrain, Dec 2007
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Inspection of Internal Tank Welds using the ACFM Inspection Method

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Abstract

This paper describes the application of the ACFM technique for weld inspection and focuses on recent experience in both Europe and Central America in the use of the technique for the inspection of steel storage tanks. Inspection of the tank floor is usually conducted using magnetic flux leakage methods but it is recognised that this cannot be applied to the detection of cracking in the welds joining the plates.

The paper describes recent developments of the ACFM technique and describes several case studies where ACFM has been used to inspect the internal plate welds on large steel storage tanks in refineries.. For weld inspection, conventional methods such as magnetic particle inspection or vacuum box testing are generally used. This paper presents comparisons of the results from ACFM with those from the conventional methods, from which conclusions are drawn as to the benefits this technique offers in terms of cost, time savings and inspection reliability.

Keywords: ACFM, Tank inspection, Weld inspection

1. Introduction

The Alternating Current Field Measurement (ACFM) technique is an electromagnetic inspection method capable of surface crack detection and sizing. The technique does not require coating removal and was originally developed in the late 1980s for use in the Oil Industry, where there was a requirement for improving the reliability of subsea inspection. The technique is fundamentally different to conventional eddy current testing and overcomes many of the difficulties of using conventional eddy currents around carbon steel welds. The ACFM technique, which is described in detail below, uses uni-directional and constant energising fields, which can be modelled. The technique therefore allows crack depth sizing to be carried out by referring the measured field disturbances to mathematical models of field disturbances around pre-defined defect (crack) morphologies. This is limited to simple crack morphologies and the technique was originally developed for the detection and sizing of fatigue cracks, which tend to be single planar defects.

When used to inspect more complex cracking, e.g. Stress Corrosion Cracking (SCC), the modelling becomes complex. Defect detection is not generally affected but the ability to determine the depth of the complex cracks is limited by the theoretical modelling constraints. It has been found however that in certain situations, where the cracking is common and of a specific nature, that the modelling of simple cracks can be extended empirically to provide reasonable estimates of crack severity. Thus, in some situations, extending the use of the technique beyond simple planar cracks has been successful.

2. The ACFM Method

The Alternating Current Field Measurement (ACFM) technique is an electromagnetic technique capable of both detecting and sizing (length and depth) surface breaking cracks in metals. The basis of the technique is that an alternating current can be induced to flow in a thin skin near the surface of any conductor. By introducing a remote uniform current into an area of the component under test, when there are no defects present the electrical current will be undisturbed. If a crack is present the uniform current is disturbed and the current flows around the ends and down the faces of the crack. Because the current is an alternating current (AC) it flows in a thin skin close to the surface and is unaffected by the overall geometry of the component.

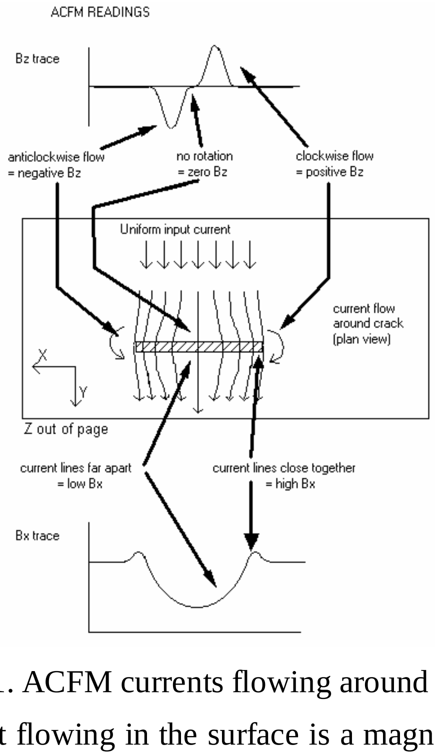


Figure 1. ACFM currents flowing around a defect

Associated with the current flowing in the surface is a magnetic field above the surface which, like the current in the surface, will be disturbed in the presence of a defect. An important factor of the ACFM technique is its capability to relate measurements of the magnetic field disturbance to the size of defect that caused that disturbance. The breakthrough came from a combination of studies at University College London, which provided mathematical modelling of the magnetic field rather than electrical fields, and advances in electronics and sensing technology.

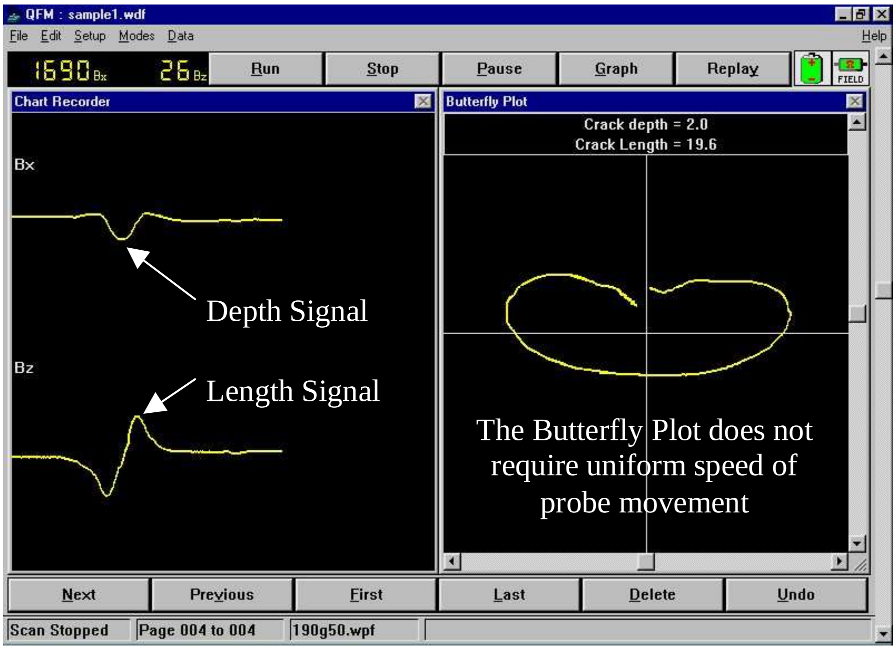
Although the magnetic field above the surface is a complex 3D field, it is possible, by choosing suitable orthogonal axes, to measure components of the field that are indicative of the nature of the disturbance and which can be related to the physical properties of any cracks present. Figure 1 presents a plan view of a surface breaking crack where a uniform ac current is flowing. The field component denoted Bz in figure 1 responds to the poles generated as the current flows around the ends of the crack introducing current rotations in the plane of the component. These responses are principally at the crack ends and are indicative of crack length. The field component denoted Bx responds to the reduction in current surface density as the current flows down the crack and is indicative of the depth of the defect. Generally the current is introduced perpendicular to the expected direction of cracking so for a shaft or axle subjected to fatigue, the current would be introduced in an axial direction to be disturbed by cracks in a circumferential direction.

In practice special probes have been developed which contain a remote field induction system, for introducing the field into the component, together with special combined magnetic field sensors that allow accurate measurement of the components of the magnetic field at the same point in space. The probe requires no electrical contact with the component and can therefore be applied without the removal of surface coatings or grime.

The mathematical modelling of current disturbances[1] showed good correlation between theoretically predicted magnetic field disturbances and those measured, hence providing the ability to make quantitative measurement of the magnetic field disturbances and to relate them directly to the size of the defect that will have caused such a disturbance. Note that the modelling was restricted to planar defects with a semi-elliptical shape, as usually encountered with fatigue cracking. The aspect ratio was not fixed, allowing, for any particular length of defect, a range of depths up to one half of the defect length (semi-circular) to be sized. Defects that deviate from this morphology may lead to error in the predicted depth.

From a practical standpoint, the technique can be applied using a single probe that can be manually moved along a component. Experience showed that with earlier electromagnetic inspection systems, for example eddy current devices, there were a number of drawbacks when used in practical situations. Many of these arose from signals from features other than cracks, leading to difficult interpretation of the signals. For example, even small amounts of probe lift off from the surface can cause large changes in a standard eddy current response. The ACFM technique has virtually eliminated this and other related problems by use of the uniform field together with careful probe and electronics design, but in particular by utilising special displays of the data. A standard PC is used to control the equipment and display results. ACFM is unique in the way data is displayed.

The plot on the left of figure 2 shows typical raw data from the crack end and crack depth sensors collected from a manually deployed probe. The right hand section of figure 2 shows this presented as a butterfly plot. In the presence of a defect, the butterfly loop is drawn in the screen and for manual operation the operator looks for this distinctive shape to decide whether a crack is present or not. Having detected a defect, the data can be subsequently interrogated to determine the depth of the crack *without* *calibration*. All data is stored by the system and is available for subsequent review and analysis. This is particularly useful for audit purposes and for reporting. Because ACFM uses a remote uniform field, it is possible to make a number of field measurements at different positions in the same field. This introduces the concept of ACFM Arrays.



Crack depth = 2.0
Crack Length = 19.6

Scan Stopped
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Depth Signal

Length Signal

The Butterfly Plot does not require uniform speed of probe movement

Figure 2. Typical ACFM signal response to a defect

2.1. ACFM Arrays

A conventional ACFM probe contains a field inducer and a pair of sensors (generally denoted Bx and Bz). In its simplest form an ACFM array probe contains multiple sensor pairs operating with a single (larger) field inducer, as shown schematically in Figure 3.

A linear array can then be swept over the component to provide inspection of the scanned area. With a single field the inspection is limited to a particular orientation of defects (predominantly oriented along the direction of scan). To overcome this limitation it is possible to incorporate other field inducers in the array probe in order to allow a field to be introduced within the sample in other orientations. This is particularly useful in situations where the crack orientation could be unknown or variable. In this case additional sensors, denoted By, are also incorporated in order to take full advantage of the additional input field directions.

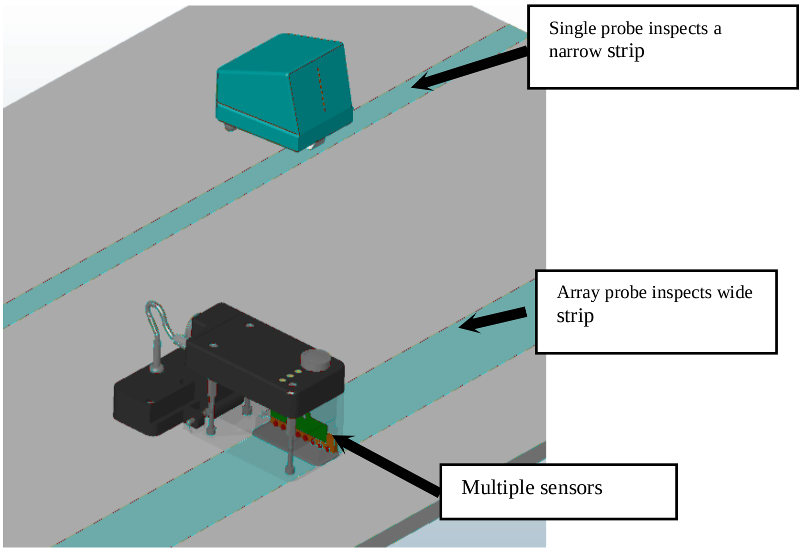

Figure 3. Schematic showing different coverage from manual and array probes

3. Application of ACFM to Weld inspection

The ACFM method is used in many weld inspection applications, both above and below water. This means probes can be sealed against the environment and so can be used with reduced cleaning compared to conventional methods. The presence of grease and other oily deposits will not adversely affect the performance of ACFM unless the deposit forces the probe to be scanned above the surface, in which case the effect is similar to that of a coating whereby the sensitivity of the system is reduced if the standoff is several millimetres.

When inspecting for cracks it is normal to inspect the weld toes and, if the weld cap is large, often weld cap scans are also required. Weld inspections are often carried out with simple probes but if large weld caps require inspection, array probes can be used to allow both toes and the weld cap to be inspected in a single pass.

4. Application of ACFM to tank inspection

Steel storage tanks are commonly used for the storage of a wide range of liquids including crude and processed hydrocarbons. These are fabricated using steel plates welded together. The tanks are circular in plan and so the floor plate layouts are often quite complex and include butt and lap welds. The weld between wall and floor is generally more uniform and can be a simple fillet weld.

Several applications are described below.

4.1. Inspection of large capacity above ground oil storage tanks in France (over 40 metres up to 92 metres outer diameter)

Figure 4. Large capacity above ground oil storage tank

In some cases, leakage due to cracking at the weld between the wall to tank floor plates had been reported. Failure analysis investigations indicated that the cyclic stresses induced by loading and unloading, together with the condition of the base slab, can lead to development of cracks at the weld toe of the internal fillet weld on the tank floor plate side. Standard floor scanning inspection methods used for corrosion thickness monitoring are not able to examine the welds areas due to noise level, neither are they suitable for crack detection. Conventional crack detection techniques such as vacuum boxes and magnetic particle testing (MPI) are time consuming and require a lot of cleaning and surface preparation. In addition petrochemical companies routinely use thick epoxy coating over the tank floor and this would need to be removed before magnetic particle inspection could be applied.

Figure 5. Encoder array probe used to inspect wall to floor weld

ACFM was selected initially for crack detection on the internal fillet weld connection between the wall and floor where cracking is expected. Inspections were carried out using a battery powered ACFM instrument and a small array probe known as an encoder weld probe, which contains three rows of sensors, as shown in Figure 5. The first sensor (located under the encoder belt) is scanned along the weld toe, the other sensors inspect the parent plate approximately 15mm and 25mm away from the toe. The integral encoder can be used to provide a record of distance travelled.

To allow faster scanning and to be tolerant to the roughness of surface, the encoder option was disabled from the software for the first inspection pass. When a defect was detected an additional scan was performed locally with the encoder enabled for sizing purposes. The encoder allows the length of the crack, and its distance from a starting datum, to be measured directly from the software rather than having to physically locate the crack ends.

Since the requirement was to detect deep defects or through cracks , the normal scan speed limitations could be relaxed (faster scanning make the detection of short or shallow defects more difficult but for large defects it is not a problem).

Because of the length of weld to be inspected, it was not practical for a single operator to both deploy and interpret the data, instead a three man team was deployed with some novel working practices! Figure 6 shows how the ACFM equipment was deployed. The ACFM operator had a backpack containing the battery powered ACFM instrument plus a halter device to support the laptop in front of him. This allowed him to make real time evaluation of the data whilst moving around the tank following the probe operator. The ‘probe pusher’ sat on a special trolley. For very large diameter tanks, a third man is pushing the trolley.

Figure 6. High speed inspection of wall to floor weld

Using this method, weld toe scanning speeds of approximately 100 metres per hour were achieved. Inspection of the critical weld area was achieved for the complete circumference of 290 metres in half a day.

In the first 6 months of 2007 around 20 oil storage tanks in France, mainly in refineries, were inspected using the ACFM.

In addition to the floor to wall welds, some customers request inspection of the weld seams on overlapping floor plates. TSC Inspection Systems have developed a compliant array probe specifically designed for such application. This probe can be set to accommodate a wide range of shapes and allows the complete weld region to be scanned without introducing excessive lift off.

Figure 7 Compliant array probe inspecting a floor lap weld

Some specific inspection results are given below:

4.1.1. RESULTS – Tank 1

On one large capacity 92 metre diameter tank two closed cracks with a total length of 3 metres were detected at the weld toe during high speed scanning. The high drop of Bx signal amplitude (Figure 8)and subsequent calculations indicated a through crack. Visual inspection did not indicate any cracking, due to the epoxy coating in place. After removal of the coating, magnetic particle testing confirm the presence of the crack along the weld toe with branching toward the base metal of the tank floor plate.

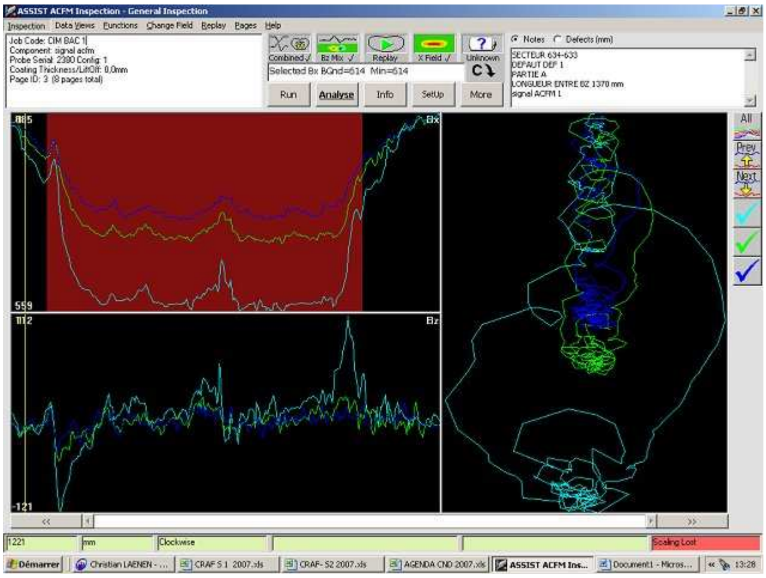

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Figure 8. Large defect signal from crack in wall to floor weld

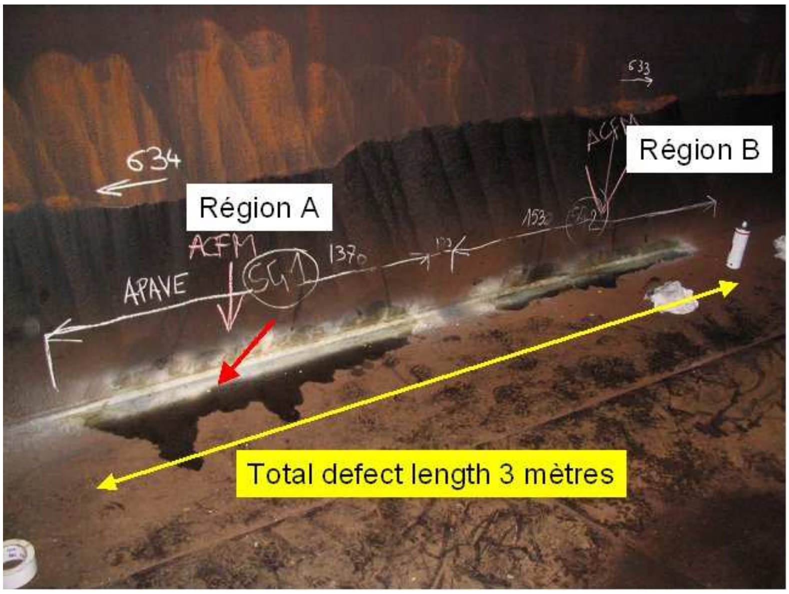


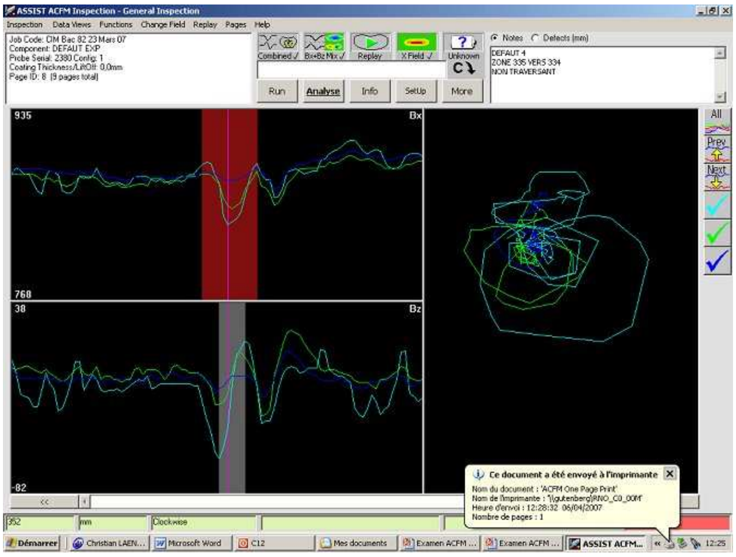
Figure 9. Defective region

4.1.2. Results Tank 2

On one large capacity 74 metre diameter tank one through toe crack 340 mm long was detected without removal of a thick epoxy plus fibre coating.

4.1.3. Results Tank 3

Conventional ACFM signals were detected along the weld toe on non coated plate. Close visual inspection found localized corrosion developed under the weld bead as shown in Figure 10



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DEFAUT 4
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Figure 10. Signals from defect at weld toe

Figure 11. Localised corrosion under weld toe

4.1.4. Results Tank 4

ACFM data signal analysis allowed experienced operator to detect corrosion patches existing under coating when seen by several rows from the array probe.

4.1.5. Experience from Tank Inspections carried out in France

When looking for large defects, high inspection rates can be achieved with scanning speeds up to 100m per hour. This is much faster than MPI where typically inspection of the wall to tank floor weld would take approximately 1 hour for a length of 10 metres and in addition require significant cleaning and removal of any protective coatings.

If crack detection is limited to the floor to wall weld, very quick turnaround times can be achieved with ACFM. A two man team can achieve inspection of 2 to 3 large tanks in one day. 100% inspection of overlapping floor welds can take a long time if scanned manually. Using array probes improves this and makes 100% tank floor weld inspection feasible. A 32 metre diameter tank at a refinery was inspected (100% of tank floor weld and wall/ floor attachment) in a single day using two, two man ACFM teams.

Although ACFM is usually used for crack detection, experience has shown that in some cases, when using array probes, surface corrosion can also be identified under coatings. Also caustic stress corrosion cracking has been identified on a carbon steel tank floor. This was not detected by vacuum box nor by colour contrast dye Penetrant Testing (PT) or MPI. After ACFM detection (large signal due to branched multiple shallow cracks) fluorescent MPI has been used to confirm the defects.

4.2. Inspection of large Diameter storage tank in Mexico

ACFM weld inspections were carried out on a 500,000 barrel capacity tank. The inspections involved complete inspection of both floor and floor to wall fillet welds, a total weld length of more than 3000 metres.

Some leaks had been suspected and routine inspection methods had been applied during routine maintenance periods, over several years, in an attempt to identify these. Magnetic Flux Leakage (MFL) had been applied to the floor plates, magnetic particle testing and Vacuum box testing had been applied to the floor lap welds and magnetic particle and Liquid penetrant testing had been applied to the floor to wall welds.

A review of the MFL results suggested that there was insufficient corrosion present on the floor plates to create a leak and so attention was then focussed on the tank welds (routine tank floor inspection with MFL cannot inspect the welds for cracks). Unfortunately deformation of the plates meant that in the vacuum box could not be used on some lap welds. The configuration of the floor to wall welds also prevented it being applied there. The results from MPI and PT gave some linear indications but from these it was impossible to establish whether any were sufficiently deep to cause leakage. Consequently none of the conventional inspection methods which are usually applied could be carried out with a high confidence of detecting a leak at a weld. The maintenance engineers then searched for a method that could be deployed in the tank environment with a high degree of confidence of finding a through crack. Following the successful use of ACFM to other applications within the Oil and Gas industry in Mexico, ACFM was selected in an attempt to find a solution.

An inspection plan and a procedure were developed to inspect the 3,000 m of weld with the objective to detect the leak that until now had proved undetectable. A 3 man team was chosen to perform the inspection, one ACFM technician and two helpers to scan the welds. The equipment used was the ACFM Amigo and two standard probes, a standard weld probe (Fig 12), and a micro pencil probe. These are conventional manual probes and do not contain any encoding device.

Fig 12. Inspection of floor weld with standard weld probe

Initially a coverage of 60m per day was achieved but as experience was gained, this was increased to 120-130m per day. The total time taken to inspect the complete the inspections was 25 days.

4.2.1. Results

During the inspection a total of 12 crack indications were found with ACFM, one of which was a through wall crack, and hence responsible for the leak. The other, non-through cracks were considered to be fatigue cracks. Of these indications, 10 were found in the floor welds and two in the floor to wall welds. Indication lengths were between 11 and 40 mm and the depths ranged from 1.3 to 3.1 mm. All indications were repaired and afterwards the repaired weld sections were inspected again with ACFM to verify that the indications had been completely repaired.

The leak was found in the floor to wall weld section, which is the section that is the most difficult to inspect. All indications were recorded within the ACFM software and stored for review or future analysis.

4.2.2. Experience from Tank Inspections carried out in Mexico

Inspecting such a large amount of weld is relatively unusual for ACFM and it was necessary to adapt the procedures accordingly. In addition to searching just for a through crack that caused the leak, it was considered important to detect other cracking, cracking that could in the future lead to leaks. For this reason, there were limits to the speed of scanning that could be achieved whilst still maintaining the ability to detect smaller cracks.

These results were extremely positive for the ACFM technique and the plan now is to incorporate the ACFM technique into the routine tank inspection procedures.

5.Conclusions

The ACFM inspection method has traditionally been used for the inspection of welded structural connections and small vessels, generally involving relatively short lengths of welds. The application to large storage tank inspection introduces a requirement to inspect large lengths of weld. By adapting procedures, and working practices, the examples above indicate that large lengths of weld can be inspected relatively quickly with this technique, whilst achieving excellent results.

The ability to inspect through coatings, and with reduced cleaning requirements compared to conventional methods, can save on overall costs and time out of service. Of course it is not just an issue of cost comparison, ACFM has been demonstrated to be capable of detecting through wall cracking where sometimes conventional tank inspection techniques have failed.

The examples demonstrate a range of probes being deployed, from simple manual probes to more complex multi channel array probes. All of the probes used are standard probes intended for general weld inspection applications. Given the large lengths of welds present in a tank, especially if all floor welds are to be inspected, it is possible that advantages could be gained by developing special probes to suit the particular geometries encountered inside large storage tanks. Further developments in instrumentation will also allow scanning at even higher speeds.

References

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