Application of (Alternating Current Field Measurement) 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 uniform and can be a simple fillet weld.

Several applications are described below.

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

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.

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.

![Image](image_url)

**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. A compliant array probe has been developed 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:

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.

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

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.
Figure 10. Signals from defect at weld toe

Figure 11. Localized corrosion under weld toe
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.

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.

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 focused 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 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](image)

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.

**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.
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.