Applications of ACFM for Weld Inspection by ROV

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Abstract
The ACFM technique was originally developed to provide accurate depths of fatigue cracks found in offshore welded structures using underwater MPI. However the technique is now specified widely across the offshore industry for both detection and sizing of surface breaking cracks in welded structures.

It is still used extensively for subsea inspection deployed by diver but more recently is being deployed remotely using ROVs. For topside applications, the remote deployment opportunities are exploited using rope access. This paper describes some typical recent applications of ACFM for underwater inspection.

Keywords: Subsea inspection, ACFM, ROV, underwater

1. Introduction

The Alternating Current Field Measurement (ACFM) technique was originally developed to provide accurate depths to structural engineers for fatigue cracks found by underwater MPI in offshore welded structures. Although the technique can be used to detect and size surface-breaking defects in any metallic component, it is still mainly used for inspecting welded joints in carbon steel, particularly when the structure is painted or coated since ACFM does not require removal of such coatings.

The technique is now widely used in topside applications, such as inspection of drill-string threads, refinery pipework, crane welds, but subsea applications remain important and provide the most difficult challenges. This paper describes some typical recent applications of ACFM for subsea inspection using remotely operated vehicles (ROVs).

2. Background To ACFM

Alternating Current Field Measurement (ACFM) is an electromagnetic technique capable of detecting and sizing surface breaking cracks in metals, developed over 20 years ago [1]. The basis of the technique is that an alternating, locally uniform current is induced to flow in the component under test. Because the current is alternating (with typical frequency in the order of $10^4 \text{ Hz}$) it flows in a thin skin close to the surface. When there are no defects present the electrical current will be undisturbed, but if a surface-breaking crack is present the uniform current is disturbed and flows around and under the crack. Associated with the current flowing in the surface is a magnetic field above the surface that will also be disturbed in the presence of a defect.

Figure 1 presents a view of a surface breaking crack where a uniform alternating current is flowing at right angles to the plane of the defect. The field component denoted $B_z$ in Figure 1 (normal to the surface) is zero in a uniform field, but non-zero components are generated by circulating current flows around the ends of the crack. These flows are clockwise at one crack
end and anti-clockwise at the other, producing positive and negative signals when a probe is scanned along the line of the defect. The distance between these \( B_z \) signals is therefore indicative of crack length. The field component denoted \( B_x \) (parallel to the surface and perpendicular to the current) responds to the reduction in current surface density as the current flows away from the deepest part of the crack and is therefore indicative of the depth of the defect. In order to estimate defect size the only two measurements required are the percentage reduction in \( B_x \), and the distance on the component between the locations of the maximum and minimum values in \( B_z \).

A standard PC is used to control the equipment and display results. The plot on the left of Figure 2 shows typical raw data from the crack end (\( B_z \)) and crack depth (\( B_x \)) sensors collected from a manually deployed probe. The right hand section of Figure 2 shows the same data presented as a so-called butterfly plot, in which \( B_x \) is plotted against \( B_z \). In the presence of a defect, a loop reminiscent of a butterfly is drawn in the screen.

ACFM has now become well established, particularly in the oil, gas and petrochemical industries, for routine in-service weld inspection because it offers many advantages over more established inspection methods. The primary one is that little or no surface preparation is needed for an inspection. Paint and other protective coatings several millimetres thick can be left on, saving a lot of time normally spent removing and reapplying such coatings. Further time is saved through the relatively simple scanning method required, and also through the fact that the ACFM response is larger for deeper defects, so that analysis/repair effort can be concentrated on the most severe defects and insignificant ones can be ignored. Finally, all data, system settings, inspector notes etc., are stored on the computer allowing audit of all inspections, 3rd party review when required, and year-on-year comparisons of defect signals. It has been reported that all these can give rise to cost and time savings of up to 60% compared to wet fluorescent magnetic particle inspections (WFMT) [2]. ACFM has proved itself in inspections on offshore platforms, bridges, cranes, ship’s hulls, train bogies and many similar welded structures [3-5].

Recent papers have reported on the advances made in array probe technology, which allows more rapid inspection of uniform geometries such as oil storage tank welds [6] and furnace tubewalls [7]. However, the most challenging inspection tasks remain those found underwater. A selection of typical inspection problems, and the systems developed to tackle them, are included here.

3. Inspection by ROV

There is an increasing requirement to avoid the use of divers for inspection tasks in favour of deployment by ROV. There are a number of reasons for this. In some cases the depths at which inspections are required are simply too deep for a diver; in other cases, divers are more expensive to use (especially where saturation diving is needed); or it is simply a matter of avoiding unnecessary risk to divers.

However, replacing a diver with an ROV is not straight forward. Consideration has to be given to how the ROV can deploy the inspection tool involved. There are basically three methods by which an ROV can carry out an ACFM inspection: mimicking a diver scanning a simple probe,
using so-called pick-and-place probes, or deploying an array probe with a separate scanning system. Examples of each of these approaches are given in the remainder of this paper.

Figure 1. ACFM currents flowing around a defect and signals from scan along the defect

Figure 2. Typical ACFM signal response to a defect
3.1 Simple Scanning

For ACFM inspection, a diver moves the probe along the weld, keeping the probe in a particular orientation. This process will normally be repeated for both weld toes and also for the weld cap. The speed of probe movement is not critical to the inspection, and uneven speeds can be tolerated, making it possible to replicate a diver using the manipulator of an ROV. However, it is important to closely follow the weld with the probe, since a standard probe will only detect defects within 5 to 10mm of the scan path. This makes it extremely difficult to carry out inspections of the complicated 3-dimensional curve of a weld between two tubular members on an offshore platform. Some success was achieved in trials using a complex manipulator and software to map the coordinates of the members, but this was using an ROV sitting on a tank floor. In the field, the extra complication of keeping the ROV fixed relative to the inspection site means that it has only been possible to inspect simple welds with a standard probe.

One example of the successful deployment of a standard pencil probe by ROV manipulator is shown in Figure 3. In this case, the ROV was able to sit on the sea-bed, and the weld being inspected was short and straight.

In situations where simple scanning is possible, there are big advantages. In particular, data can be sampled at high resolution along the scan path, so it is possible to detect defects at the limit of the technique (typically 10mm long by 1mm deep at a weld). Also, by using a small probe it is possible to get into tight access geometries (although not as tight as for the same probe deployed by a diver).

The main disadvantages of this approach are the limitations to simple welds, the need for good stability for the ROV, and the fact that (unless there is a good force feedback system) it is very easy to damage probes.
3.2 Pick-and-place Probes

The second method of inspecting by ROV, which gets round the problems of limited dexterity of a typical manipulator and limited stability of an ROV, is to use so-called pick-and-place probes. These are probes which contain one or more rows of sensors aligned in the direction of the weld. Figure 4 shows two examples of probes for different geometries.

![Figure 4. Pick-and-place probes for node (left) and T-butt (right) inspection](image)

During an inspection, the probe is placed in contact with the weld by the ROV and held steady for a few seconds while data is read from the sensors. The probe is then lifted off the surface and put back a little further along the weld to take more data. In this way, the weld can be inspected in a series of snapshots, taking care to ensure some overlap of the sensitive part of the probe between placements so that no part of the weld is missed.

One complication with this approach is that the area inspected in one probe placement is quite limited, particularly for a flat probe inspecting a curved surface. A defect which is shorter than the length covered by the sensors can be contained in a single data page, making analysis and sizing easier. However, longer defects will produce signals over two or more placements, making it more difficult to analyse them. To get round this problem, software has been developed to merge data together from adjacent probe placements, as shown in Figure 5.

![Figure 5](image)

The advantages of pick-and-place probes for inspection are that it is possible to inspect more complicated geometries than with a standard scanned probe, and also the probes can be made more rugged to cope with deployment by ROV.

The main disadvantages of this approach are that data resolution along the weld is limited to the fixed spacing between the sensors. This means that short cracks may not be detected, and the measurement of defect length will only be accurate to the nearest sensor spacing (typically 5 to 10mm). Other disadvantages are that data collection can be slow, probe lengths have to be limited to avoid lift-off under the probe ends when inspecting curved surfaces, and data interpretation is more complicated than for standard probes.
3.3 Scanner Sub-System

In order to try to retain the advantages of good data resolution from a scanned probe, while avoiding the drawbacks of deployment by an ROV manipulator, recent inspections have made use of scanner frames. These are designed to be put in place by the ROV, but then probe movement is accomplished by the scanner rather than the manipulator. The ROV may be used to carry the associated electronics and handle communication to the surface, but otherwise stands off until an inspection is complete and the scanner can be collected or moved to another site.

In these situations, it is possible to use standard single probes, but it is more usual to use so-called paintbrush array probes, which contain rows of sensors aligned perpendicular to the weld so as to inspect a wide band of the component in one pass. Figure 6 shows one such system, which contained ultrasonic sensors as well as ACFM probes to inspect pipeline girth welds.

Figure 7 shows a system designed to inspect a much longer circumferential weld above the mud-mat on a jack-up rig. In this case, the scanner was positioned to inspect one short section of the weld at a time, with the ROV picking the scanner up and replacing it further along to inspect the next section. The weld being inspected was also not flat, so three separate array probes were installed in the scanner, one to inspect each toe/HAZ and one to inspect the cap. The probes were placed in a staggered line to ensure overlap between the scans.

This was the first commercial use of multiple ACFM array probes connected to a single instrument, and required extensive modifications to the analysis and display software.
4. Summary

The ACFM inspection method was originally developed 20 years ago for the inspection of welded steel joints and this remains its main application. The ability to inspect through paint and other coatings with reduced cleaning requirements compared to conventional methods, as well as report on defect depth allowing prioritisation and scheduling of repairs, saves on inspection time as well as time out of service.

In recent years, major developments have taken place in underwater array probe technology, software, and data processing to allow deployment by ROV. The examples given in this paper demonstrate the various options available, depending on the application. It is expected that the challenges offered by the subsea environment will continue to push developments in technology and deployment systems.

References