A Review on Underwater Inspection of steel liner welds in hazardous environment

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***Abstract*—Underwater inspection in offshore and subsea application is an area of research and understanding where, many problems are still unsolved. In the present paper, a brief description of the different commercial NDT inspection techniques has been made. The problems in underwater inspection have also been discussed in context to the existing inspection techniques. Detailed description of an Alternating Current Field Measurement (ACFM) inspection technique along with an example where ACFM probe used in hazardous environment has also discussed.**
***IndexTerms*— ACFM, ACFMT,NDT, Weld Inspection.**

I. INTRODUCTION

Underwater inspection processes have become increasingly important in almost all subsea and for structural application. Although, a large number of techniques are available for inspection in atmosphere, many of them cannot be applied in radiation environment, offshore and subsea application where presence of water is of major concern. In many cases it is impossible to inspect them with intrusive techniques and the need of advanced underwater in-service inspection tools and self-monitored equipment's has become imperative.

ACFM is widely used for detection and sizing of surface-breaking cracks in structures such as oil and gas platforms, process plant, pressure vessels, storage tanks, bridges and theme park rides. It is used for general area inspection, thread inspection, applications at high temperatures or in radioactive environments [4], but its main use remains the inspection of welds, particularly in ferritic steel. ACFM meets the need for fast, low cost, non-destructive inspection without sacrificing performance. This study is carried out to select suitable& effective technique for underwater inspection of stainless steel liner of a pool having nuclear fuel.

II. COMMON NDT METHODS

A. Volumetric Examination Methods

1. Ultrasonic Testing -UT

Ultrasonic inspection uses high frequency sound waves to detect imperfections or changes in Properties within the materials. It can also be used to measure the thickness of a wide range of metallic and non-metallic materials where access from one side only is available.

2. Radiography Testing -RT

Radiography uses an x-ray device or radioactive isotope as a source of radiation which passes through the material and is captured on film or digital device. After processing the film an image of varying density is obtained. Possible imperfections are identified through density changes.

B. Surface Examination Method

1. Visual Inspection –VT

Components are scanned visually, sometimes with the aid of low or high power lenses, fiberscopes, cameras and video equipment, to determine surface condition. It is Oldest of all the methods.

2. Liquid Penetrant -PT

In Liquid Penetrant the test object or material is coated with a visible or fluorescent dye solution. The excess dye is removed from the surface and a developer which acts like a blotter is applied drawing penetrant out of imperfections open to the surface. With visible dyes, the vivid color contrast between the penetrant and the developer is used. With fluorescent dyes an ultraviolet lamp is used to make the 'bleed out' fluoresce brightly allowing the imperfection to be seen readily.

3. Magnetic Particle -MT

Magnetic Particle inspection is used to identify surface and near surface discontinuities in ferromagnetic materials such as steel and iron. The technique uses the principle that magnetic lines of force (flux) will be distorted by the presence of a discontinuity. Discontinuities (for example, cracks) are located from the flux distortion following the application of fine magnetic particles to the area under test.

4. Eddy Current -ET

In eddy current testing electrical currents are generated in a conductive material by an induced magnetic field. Distortions in the flow of the electric current (eddy currents) caused by imperfections or changes in a material's conductive properties will cause changes in the induced magnetic field. These changes, when detected, indicate the presence of the imperfection or change in the test material.

C. Integrity Examination Method

1. Leak Testing -LT

Leaks can be detected by using electronic listening devices, pressure gauge measurements, liquid and gas penetrant techniques or a simple soap-bubble test. Several techniques are used to detect and locate leaks in pressure retaining components such as pressure vessels and pipelines.

2. Acoustic Emission Testing-AET

When a solid material is stressed, growing imperfections, if any within the material emit short bursts of acoustic energy called "emissions". As in ultrasonic testing, acoustic emissions can be detected by special receivers. Emission sources can be evaluated through the study of their intensity, rate and other characteristics. The growing defects can be located by triangulation technique (similar to earthquake epicenter location).

D. Condition Monitoring Method

1. Thermography – Infrared Testing - IR

Thermography enables the thermal profile of an item, machine or building to be presented in a graphic form which allows a working temperature assessment to be derived. From this, variations in the material or component temperature are identified, enabling working limits or corrective actions to be identified.

2. Vibration Analysis - VA

The rotary machines produce vibration noise. By monitoring the frequency, amplitude etc. of the vibration the condition of the machine can be estimated.

E. Special NDT methods

NDT engineers and technicians also use magnetic resonance imaging, vibration monitoring, laser ultrasonic, holography, computed tomography as well as many other specialized methods for specialized applications.

III. PROBLEMS ASSOCIATED WITH UNDERWATER WELD INSPECTION OF NUCLEAR FACILITIES

- Visibility.
- Depth.
- Turbulence.
- Rust and corrosion products.
- Access on the other side of component.
- Radiation field.
- Remotely operated system.

IV. CHARACTERISTICS OF A GOOD UNDERWATER INSPECTION

- Requirement of inexpensive inspection equipment, low cost, easy to operate and flexibility of operation in all positions.
- Minimum electrical hazards.
- Permit good visibility.
- Operator should be capable in supporting himself (inspection module should be rigidly supported to eliminate chances of background noise pickup).
- Easily automated.
- Inspection Data transmission to remote location.

V. THE ACFM METHOD

The Alternating Current Field Measurement (ACFM) technique [1] 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. 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.

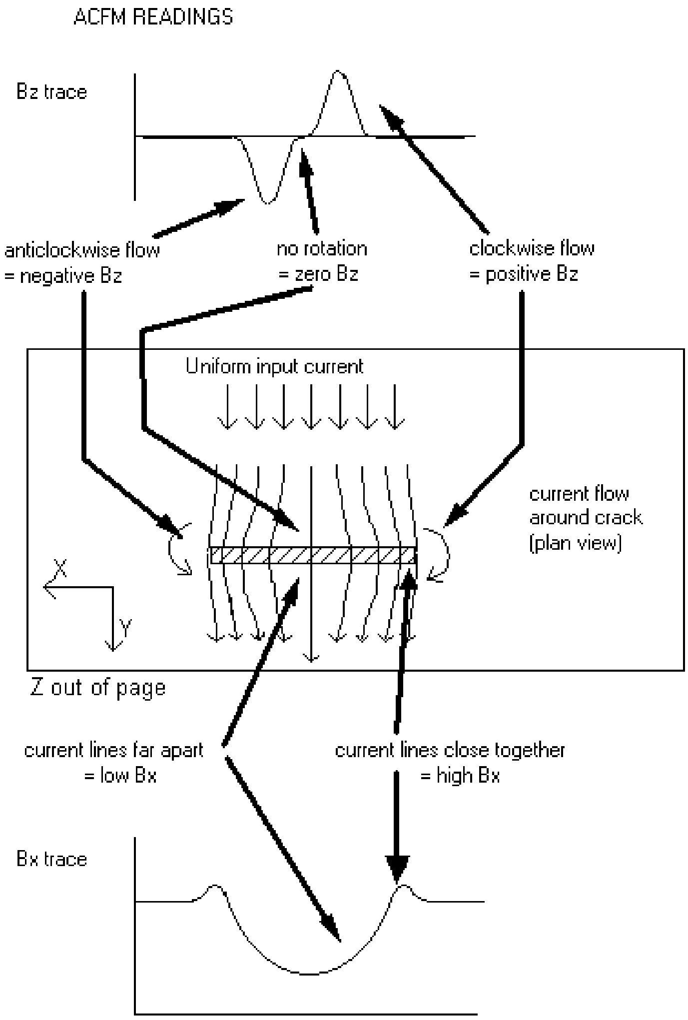

Fig5.1 ACFM currents flowing around a defect

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. Figure5.1 presents a plan view of a surface breaking crack where a uniform ac current is flowing. The field component denoted Bz in figure5.1 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 disturbances1 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 utilizing 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 figure5.2 shows typical raw data from the crack end and crack depth sensors collected from a manually deployed probe. The right hand section of figure5.2 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.

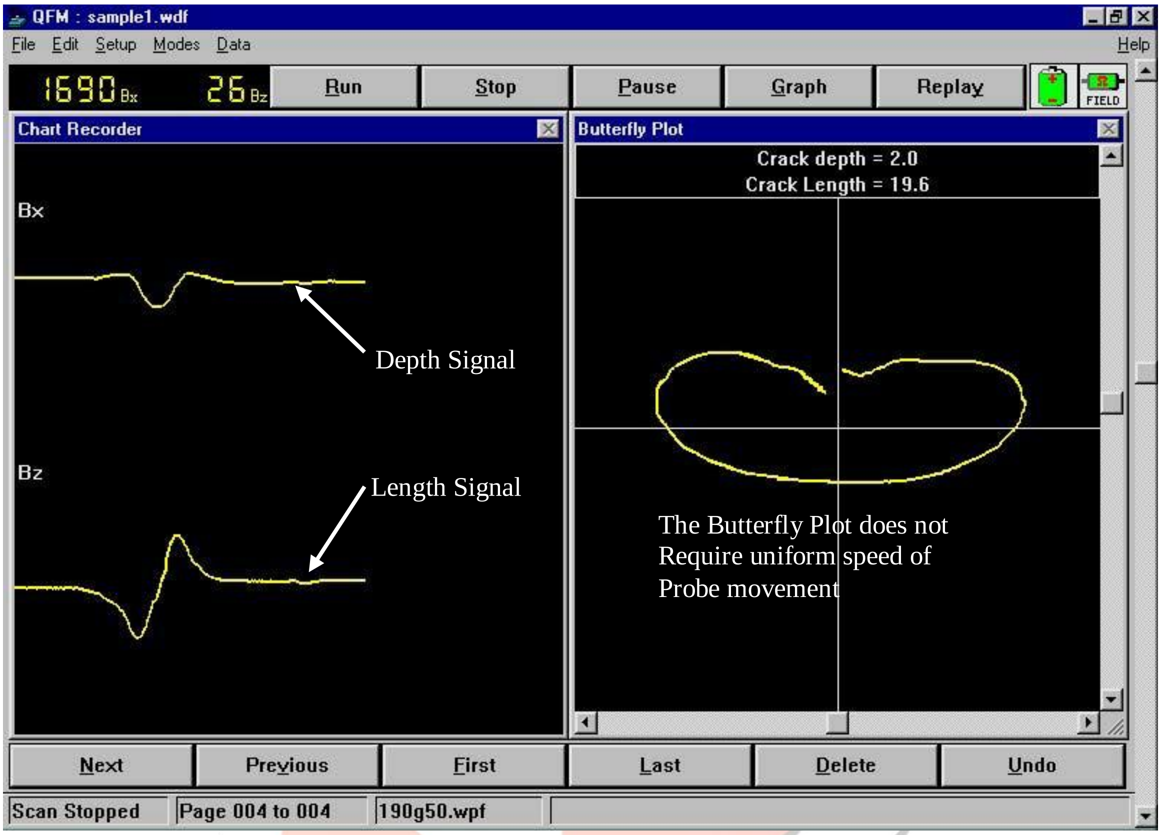

Fig5.2 Typical ACFM signal response to a defect.

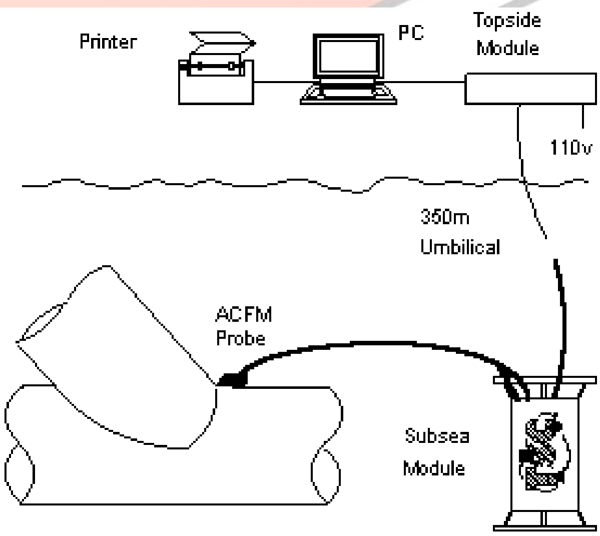

Fig5.3 Schematic Layout of Underwater ACFM System[1].

A. 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 5.4. 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.

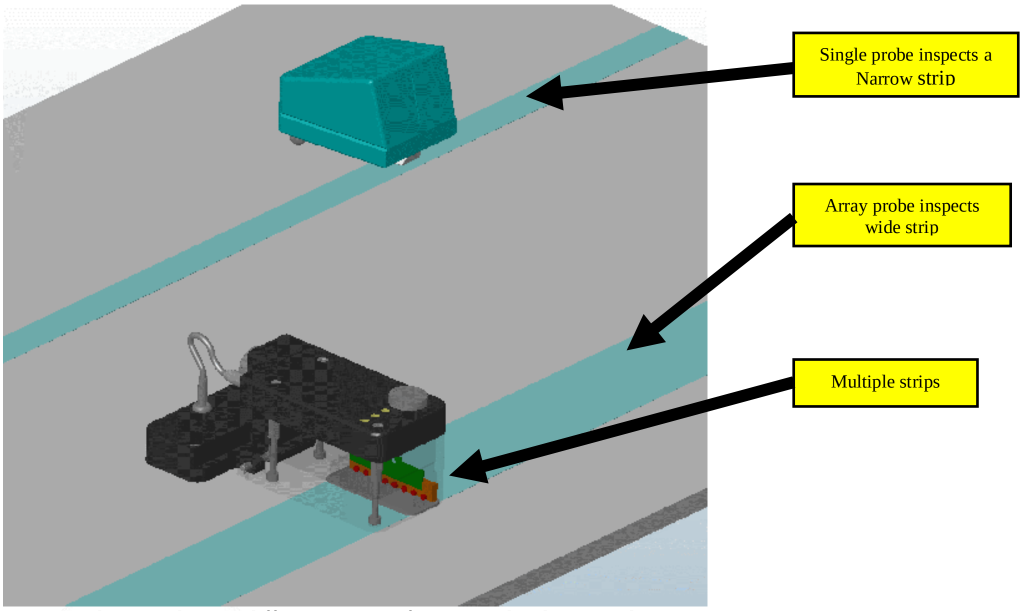

Fig5.4 Schematic showing different coverage from manual and array probes

B. 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 millimeters. 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.

C. Capabilities

- Can work with a low dexterity manipulator.
- Rapid scanning using a hand-held probe.
- Reliable crack detection and sizing (length and depth) [3].
- Reduced cleaning requirements with no need to clean to bare metal.
- Capable of inspecting corroded surfaces, or through non-conducting coatings several millimeters thick.
- Software can be made for ease of operation and compatibility with other so full data storage for back-up, off-line view and audit purposes.
- Access to a wide range of geometries using TSC’s range of active subsea probes.
- Probes with embedded serial numbers to simplify operation and reduce likelihood of operator error.
- Capable of operating at water depths up to 300m.
- High temperature capability.
- ROV use.

D. Advantages over conventional NDT techniques for underwater application

- ACFM provides information on defect length and depth.
- ACFM can be used in any light level and can therefore be used in 24 hour operations.
- ACFM is faster to deploy.
- ACFM can be deployed in most sea conditions and, unlike MPI, is not limited by currents, swell or poor visibility.
- ACFM provides electronic records of all inspection data which is available for subsequent review or audit.
- Require no electrical contact.
- Require no calibration.

E. Applications

- Structural weld inspection
- Offshore cranes
- Storage tanks floor & roof ‘lap’ joints
- Storage tank annular welds internal & external
- Vessel nozzles

F. Limitations

- High capital cost of the equipment.
- Operator requires a higher level of training and to possess knowledge of computer operation and welding as well as NDT.
- Sensitivity to shallow cracks is less.
- Complex signals can arise from tight geometries, plate edges and branched cracks.

VI. CASE STUDY: APPLICATION OF ACFM TECHNIQUE IN NUCLEAR ENVIRONMENT

A. Influence of ionizing radiation on the behavior of the probe

Tests were carried out in April 2005 at CIS BIO in Saclay[5], France, to investigate the effects of radiation on the ACFMT array probe. The tests were designed so that any effect in ACFM response could be monitored while exposing the probe until failure. The probe was mounted in a motorized test frame that was able to scan the probe repetitively over a test sample while the probe was exposed to a cobalt gamma-ray source (Figure 6.1).The probe used was constructed from conventional non-radiation hardened components. Tests were carried out at dose rates of 5 Gy/h (500 rad/h), 50 Gy/h (5000 rad/h) and 500 Gy/h (50,000 rad/h). The probe survived 30 minutes at 500 Gy/h rate and failed with a total exposure of 600 Gy (60,000 rad). No signal quality degradation was observed during any of the tests until the probe failed. The eventual probe failure was caused by the failure of a voltage regulator. The probe has since been repaired and continues to perform well.

B. Testing in an active nuclear pool

During April and May 2005, the Alternating Current Field Measurement Technique (ACFMT) system was deployed onsite at a European nuclear power station. The transfer pool, lyingbetween the reactor pool and the fuel storage pool, was inspectedusing a combination of divers and the developed robotic vehicles. 75% of the pool welds were inspected using ACFMT. Theremaining 25% could not be inspected due to restricted accessaround access ladders.

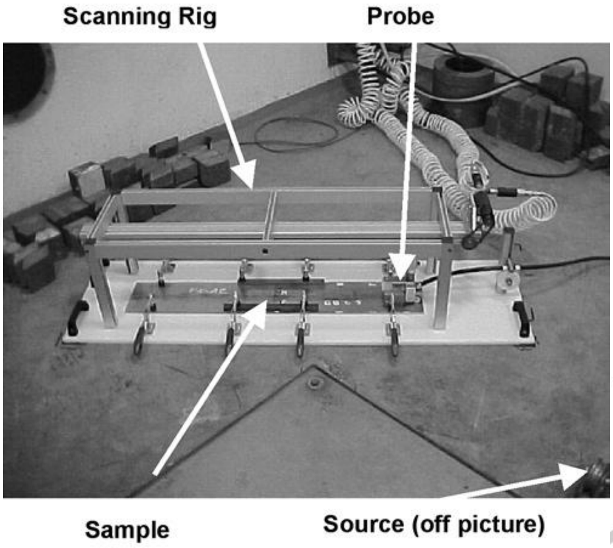

Fig6.1Test equipment during radiation exposure tests.

The system performed extremely well and 17 small indicationswere identified, none of which was deemed to be through wall.These areas will be checked by conventional techniques in thefuture when schedules permit.

VII. CONCLUSION

ACFM technique represents a significant advance in inspection technology &range from simple manual scanning through to complex automated and semi-automated systems. Compared to conventional inspection methods the use of ACFM has resulted in substantial cost savings allied with improvements in inspection reliability.An ACFMT system was successfully developed to rapidly inspect the welds of the stainless steel cladding in nuclear storage pools.

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