Crack Monitoring using ACFM

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Abstract

Key input data for Structural Integrity Monitoring (SIM) calculations are the service stresses and the crack/defect size. To satisfy the second requirement the Alternating Current Field Measurement (ACFM) technique [1] has been developed. Initially this was for the offshore oil and gas industry but it is now used very widely in other industries. ACFM allows one to detect and size surface cracks during both subsea and topside inspection. However a recent innovation for ACFM has been the introduction of array probes. Array probes have several sensors in one probe arranged in one or several rows thus allowing the collection of crack depth information from various sites along a crack in one placement of the probe. The array probe is an area or strip inspection and hence can also be used for crack size monitoring if left in place on the structure.

Array probes have now been used for both continuous monitoring and intermittent measurements and an example of these two modes of operation is given in this paper

Background to ACFM

ACFM is an electromagnetic technique for detecting and sizing surface breaking cracks. ACFM is an acronym for alternating current field measurement and was developed during the 1980's from the a.c. potential drop (ACPD) technique. The initial theoretical work was undertaken at University College London but since then the marketing of practical instruments and probes has been carried out by TSC Inspection Systems located in the UK.

Its conventional application is for the detection and characterization of fatigue cracks in and around welded joints but is increasingly used to detect a variety of surface breaking defects.

Mathematical models of the field interaction with the cracks enable the crack length and depth to be predicted. This mathematical model is based on a defect morphology that is semi-elliptical in shape, the most common shape in fatigue-induced cracks. It should be noted that the crack model is not limited to a fixed aspect ratio but the largest depth that can be determined is usually half of the crack length measurement.

ACFM has been approved by Lloyds, ABS, BV, DNV, and OCB Germanischer Lloyd for the inspection of offshore installations. ASTM has recently incorporated it as a Standard Practice for the examination of welds (E2261-03).
ACFM is recognised as a technique by ASNT and a chapter devoted to ACFM is included in the Non-destructive Testing Handbook, third edition, volume 5: Electromagnetic Testing.

Continuous Crack Monitoring

Many crack monitoring studies have been completed in the laboratory using ACPD (Alternating Current Potential Difference). These were research projects where it was necessary to monitor crack shape evolution in welded connections in order to confirm the results of fracture mechanics studies. ACPD requires electrical contact with the metal surface and hence the ACPD contacts were usually spot-welded to the test component at the weld toe.. The results from this work were of high quality and an example of early fatigue crack growth on a tubular welded T joint tested under variable amplitude corrosion fatigue [2] is shown in Figure 1. It can be seen that with ACPD it was possible to monitor early crack growth even with a connection spacing of 5 mm. This was because the crack aspect ratio was often large in this early period of crack growth. After the development of the non-contacting ACFM technique from ACPD it became possible to monitor cracks without the need to attach probes as the sensor spacing could be of the same order as the ACPD studies .

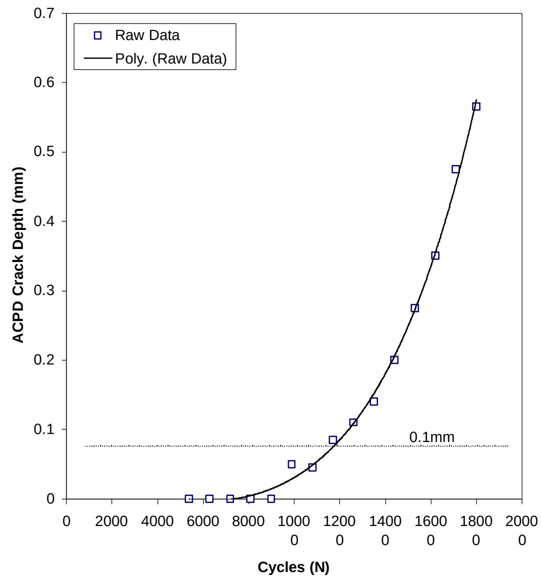

Figure 1: Early fatigue crack growth data, showing crack initiation in a tubular welded joint

In a more recent series of fatigue tests [3] this new approach has been demonstrated using array probes for monitoring. The array probes consisted of eight Bx and Bz coils arranged in a row at 10mm spacing. Four array probes were used to cover an area 160x20mm. The fatigue tests were conducted on a high strength steel (of the type proposed for use in jack ups), in four point bending at a frequency of 2Hz and a stress range of 200MPa. The specimen dimensions were 600 x 150 x 20mm and the weld had been ground to give a smooth finish.

Some detail of one of the tests is given here as an illustration of monitoring. The test occupied a total of 1.1 million cycles and the majority of the crack data occurred over the last night of the test. In this case the weld grinding had produced a long initiation period.

Figure 2 shows the interpreted ACFM array data for crack depth growth rate for the latter part of the test. The test ended in a fast fracture from a crack which appeared to be 10mm deep. It can be seen that the ACFM array probe showed a gradual increase in the crack growth rate right up to the final fracture. The final crack size was measured by visual inspection after the fracture event and found to be 10mm deep and 50mm long.

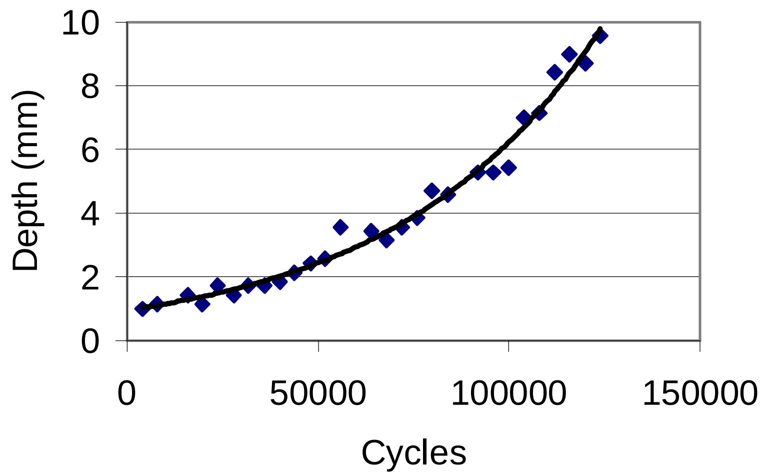

Figure 2: Interpreted ACFM array data for crack depth growth rate

It can be seen the final prediction of crack size was correct ie 10mm. However the aspect ratio was 5 to 1 (due to the absence of the weld toe stress concentration factor) and hence the early crack growth was not recorded until the crack was over 1mm deep. This problem would have occurred with ACPD as well. An alternative array system has recently been made and this utilises an array that can be periodically swept along the anticipated crack path by 10 or 15 mm. This adaptation should allow the detection and study of smaller cracks.

Intermittent crack monitoring: Coke drums

It is not always necessary to monitor continuously for SIM purposes. In some applications crack growth can be very slow. In such circumstances occasional intervention to obtain a periodic assessment of the condition is appropriate. An example of this type is the delayed coke drum.

Delayed coke drums are operated under severe conditions of cyclic heating and forced cooling that apply repetitive thermal stresses to the drum walls. It has long been recognized that the ultimate failure mechanism for coke drums is weld cracking due to low cycle fatigue caused by these thermal stresses. It is also known that coke drums distort and bulge in service and that these bulges can be used as pointers to potential weld failure areas.

Key features of the technique which lends itself to internal inspection of coke drums include its suitability for remote, robotic deployment and the ability to work on relatively dirty surfaces.

Inspection of coke drums is a specialist area and consequently TSC has linked up with CIA Inspection [4] (herein referred to as CIAI) who have developed and operate a specialized laser surface profiling system designed to internally inspect coke drums during the short time period between coke cutting and refilling. CIAI's inspection system uses a remote sensor package deployed from the coke drum's drill stem as shown in Figure 3:

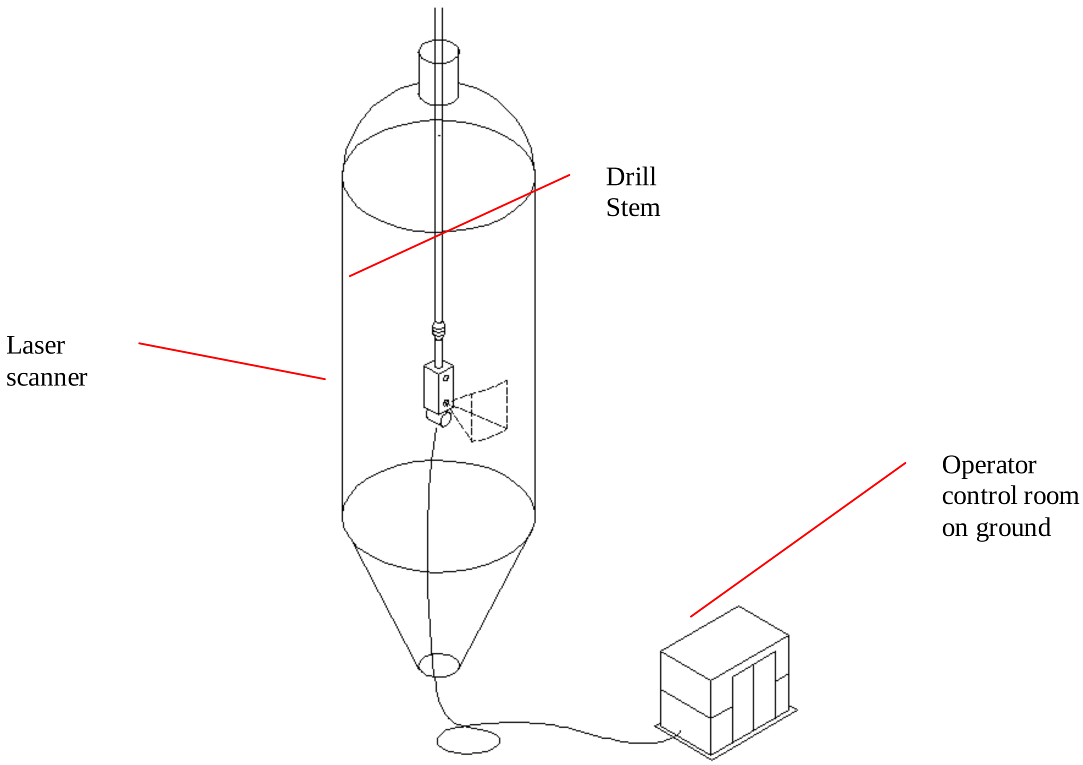

Figure 3: Coke Drum Inspection System with Laser Profiler

A colour video camera with zoom lens permits a detailed remote visual inspection of the inside of the drum capable of identifying surface flaws such as cladding defects or potential weld cracks. It was considered that the TSC ACFM technique could be deployed from this robotic system periodically to give the information on crack size needed for SIM.

Coke drum welds are quite complex as shown in Figure 4. Consequently some provisional studies have been undertaken at TSC to show the ACFM capability to determine cracks in these welds.

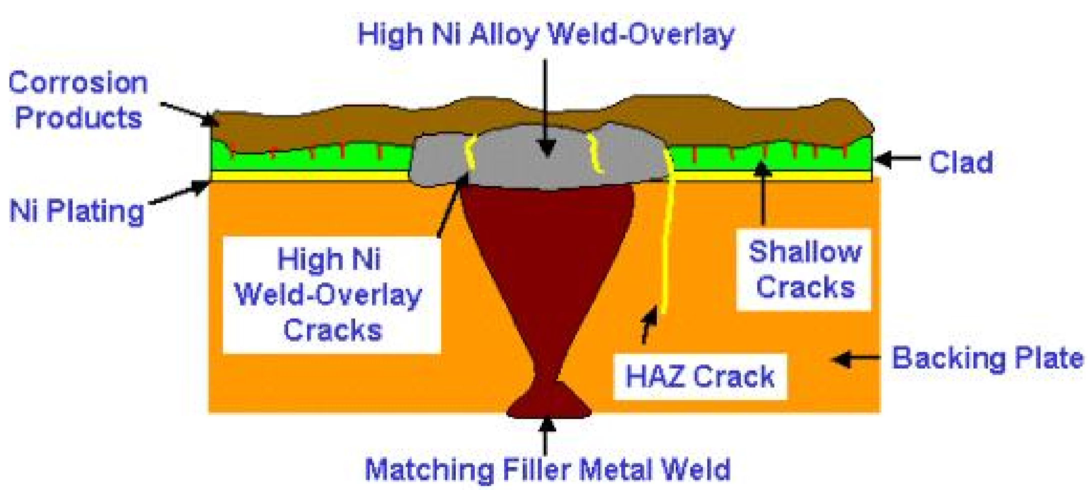

Figure 4. Low cycle fatigue crack caused in the clad restoration weld of coke drum

A development program was initiated to integrate ACFM inspection technology with CIAI's proven coke drum inspection tools. Initial tests were carried out on a sample designed to mimic the form and materials used in the welded sections of a typical coke drum. Artificial surface breaking defects were introduced into this sample by electro-discharge machining (EDM) to help in defining the probe parameters.

Detailed analysis of the ACFM system performance on the sample enabled the sensor type and operating frequency to be optimized. It was found that it was possible to detect a 7mm (0.28") long x 2.5mm (0.10") deep slot in the toe of the weld. The sensitivity in the Inconel weld cap was less than this due to the electromagnetic properties of this material and due to an increase in signal noise from the irregular weld profile. However in practice the defects are only likely to be problematical when they are deeper than the thickness of the weld cap (typically 5-6mm) and penetrate into the sub-plate.

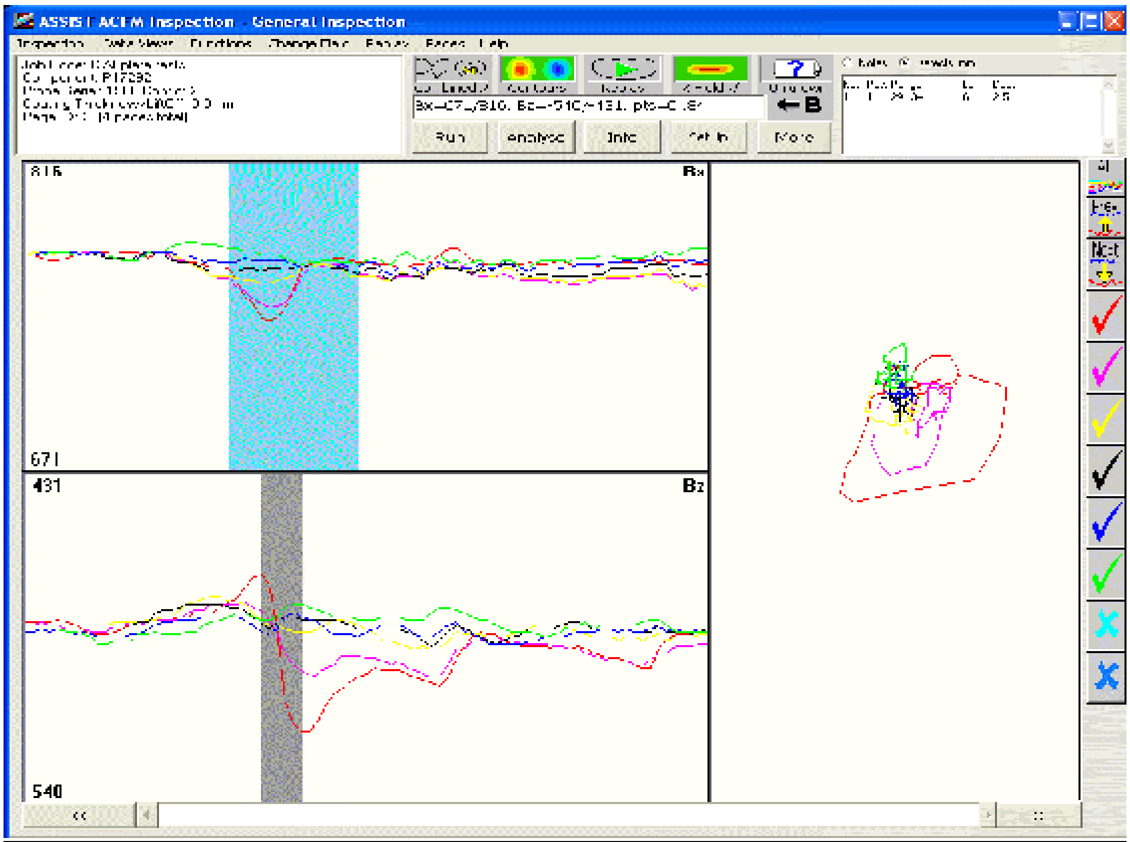

Figure 5: Screenshot showing defect in the toe of weld

The system uses a custom designed ACFM sensor head composed of an array of individual sensors incorporated into an integral package. The size and spacing of the sensors are configured depending on the target defect size and other operating factors. The requirement is to be able to scan the weld, both toes and a little into the HAZ with one pass of the probe. This is achieved by using 16 sensor pairs, which cover a width of approximately 114mm (4.5"). A typical ACFM result is shown in Figure 5.

With this newly developed remote crack detection system, management now has the capability to assess the significance of the surface indications without scaffolding, insulation removal or vessel entry. It allows the number and location of relevant indications in the drum to be measured periodically. The results of these investigations would confirm if visual indication are really cracks and it would also characterize the crack so that management could make a decision on the urgency to make a repair.

SUMMARY

Monitoring of cracks continuously and intermittently allows the continuing assessment for structural integrity. A side product of this activity is that often the quality of crack information is superior to that obtained in a single intervention. This high quality data on crack size allows the facility owner the opportunity to schedule repairs and to maximize the use of equipment. The TSC CIAI development is an example of this new approach and this will be operational in 2006.

References.

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4. CIA inspection 2399 Golf Club Road Hannon Ontario L0R 1PO Canada