The application of the Alternating Current Field Measurement (ACFM) technique for public safety applications.

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Abstract

The use of NDT is well known in the oil and gas industry, petrochemical industry, shipping and aerospace.

Theme parks are visited by thousands of people worldwide and the rides are becoming more adventurous by demand. This places a greater strain on the material being used and fracture mechanics analysis is being carried out to determine the critical defect size that can be allowed to exist. From a customer satisfaction point of view the rides must be available when the theme park is open which in some cases is all year. This means inspection techniques have to be used which are non-invasive but which can reliably detect the even smaller defects required to be detected.

Bridges are even greater people carriers, rail or road, and are often coated and have difficult access.

Interest has been recently aroused in the structural integrity of high rise buildings constructed with low toughness weld metal. The majority of buildings constructed in the West Coast of America have used this material and quite a lot especially in the California area has been subject to seismic shocks. Tests carried out have shown that these shocks would be greater than those applied during the toughness tests which produced low values. This has led to the thought that some of these buildings will have defects present in their welded joints. The problem that now exists is one of inspection and determining if defects of a significant nature are present. The Alternating Current Field Measurement technique has been used successfully to inspect through coatings and with rope access techniques and so can be applied to these public safety applications.

Introduction

The ACFM technique has been used since the late 1980's for the subsea and topside inspection of offshore oil and gas installations in both its subsea and portable form. It has been further used in other applications as its use has become better understood and the value of being able to inspect for surface breaking fatigue cracks without removing the coating has been accepted. Initially the ACFM probes produced were only suitable for the inspection of long node welds but as the application became more varied additional probes have had to be produced. An early addition was the pencil probe produced to inspect areas in welds that had been ground out to remove earlier detected defects. This probe was profiled to fit the ground out area and could detect if fatigue cracks had further propagated after their removal. During a trial organised by University College London where samples were produced to reproduce some of the difficult geometry's and access problems located in process plants, it was found that additional probes were required to gain access and detect and size the defects located within the samples. A range of mini and micro pencil probes has now been produced with straight and 90 degree access with increased sensitivity. In addition to this it was realised that the inspection of short lengths of weld also created problems in that the communication rate was too slow to produce a good representation of the weld result on the VDU screen. New software has now been produced that eliminates this problem including communication rates, which allows scanning speeds seven times faster than before. This allows greater presentation on the screen for shorter lengths of welds and faster scanning speeds for the inspection of long lengths of weld. This new range of probes and software has expanded the use of the ACFM equipment into new applications including theme park inspection, highway applications and building construction.

Alternating Current Field Measurement

The ACFM technique is an electromagnetic non-contacting technique which has been developed to be able to detect and size surface breaking defects in a range of different materials and through coatings of varying thickness. The basis of the technique is that an alternating current flows in a thin skin near to the surface of any conductor When a uniform current is introduced into the area under test if the area is defect free the current is undisturbed. If the area were to have a crack present then the current would flow around the ends and the faces of the crack. A magnetic field is present above the surface associated with this uniform current and this will be disturbed if a surface breaking crack is present. It was realised that if these disturbances could be measured they should have some relationship to the defects that had caused them. University College London carried out studies into the mathematical modelling of these magnetic fields and their associated disturbances. A good correlation was produced between the theoretically predicted magnetic field disturbances and those measured and thus showed that it was possible to make quantitative measurements of the magnetic field disturbances and relate them to the size of the defects which produced them. Special techniques are used to induce these electric currents and the components used are built into the ACFM probes Small detectors or sensors are also built into the probe which measure the magnetic field disturbances .Two components of the magnetic field are measured, the Bx along the length of the defect which responds to changes in surface current density and gives an indication of depth when the reduction is the greatest and Bz which gives a negative and positive response at either end of the defect caused by current generated poles and thus gives and indication of length. Figure 1 .A physical measurement of defect length indicated by the probe position is then used together with a software program to determine the accurate length and depth of the defect.

In order to aid interpretation the Bx and Bz components are plotted against each other and when a complete loop indication is produced this confirms the presence of a crack. This is called the Butterfly plot Figure 2 and because it is not sensitive to probe speed aids in the interpretation of the data collected and confirms defect indications. During the application of the ACFM technique actual values of the magnetic field are being measured in real time and these are used together with mathematical model look-up tables so that there is no need for calibration of the ACFM instrument using a calibration piece with artificial defects such as slots. These can be used for demonstration purposes but they are not representative of real cracks as they do not behave electrically as a crack. The slot has other disadvantages as it will not be located in a characteristic metallurgical or geometric position i.e. in the heat affected zone area between the weld metal and the parent plate and it will probably not have a characteristic crack shape.

The ACFM technique is insensitive to permeability changes and lift off and, as it does not rely on probe contact, it can be used to inspect through coatings of various thickness and material.

Applications

The ACFM technique was originally developed for the inspection of carbon steel welds on subsea structures, which were usually nodal welds . A number of probes were developed, a general purpose weld inspection probe, a 30 degree angle probe for examining tight angle geometry's and a pencil probe specially designed to examine welds that had been subjected to grinding. This was used to inspect the bottom of the ground toe of the weld to determine if defects were present and then determine their length and depth or to confirm that the defect had been removed. The technique was also used to inspect structures that had been coated with protective or anti fouling coatings so that the expensively applied coatings did not have to be removed and reapplied thus avoiding costly preparation and reinstatement. The technique was also adopted by topside inspection engineers for the inspections of process and pressurised plant systems, structural steelwork and crane pedestals. The system was used in conjunction with rope access teams allowing inspection without scaffolding and proving the usefulness of two man operations and the Butterfly plot. Inspections could be carried out up to 50 metres between the ACFM operator and the probe pusher.

The technique has also been applied to the inspection of drill threads on casing and drill tools. A special transportable system has been produced to automatically inspect the drill thread ends and classify them. This provides Go-NoGo reporting. The system is based on new ACFM array technology. A hand held probe has also been produced to inspect drill threads with the portable ACFM system.

New materials are being used for components and coatings on offshore structures but the ACFM system has now been successfully applied to ferritic steels, austenitic stainless steels, aluminium, duplex, super duplex, monel and inconel. It has also been used to inspect through the following coatings, flame sprayed aluminium, epoxy coating, standard paints, ferrite based paints and copper coated threads.
Some inspections have to be carried out when the plant is operational and ACFM has been used during inspections at -20 degrees centigrade and up to 500 degrees centigrade.

Because of the above advantages the ACFM technique has been used to inspect coated flare booms, epoxy coated pig traps, painted nozzle welds, pipe butt welds, pipe and saddle support welds and pressure vessel seam welds as well as the above mentioned inspections.

Evaluation of the ACFM technique.

Trials have been carried out with the ACFM technique to determine its ability to detect surface breaking defects and to accurately size their length and depth. Reference 1. A library of nodes was produced at the University College London , these were fatigued to produce real fatigue cracks of varying length and depth. About 200 fatigue cracks located in various geometries were produced and these were inspected with the ACFM technique together with other techniques so that a true comparison of performance could be produced. Probability of Detection curves were produced for all of the techniques and ACFM proved to have similar detection capabilities to that of MPI Figure (3). This figure shows that ACFM detection is marginally better than MPI and on assessment it was shown that MPI had four times more false calls than ACFM. Crack length comparisons showed that there was little difference between ACFM predictions and MPI Figure (4) and that the correlation between predicted and actual crack depths was also good. Figure (5). Reference 2. Some of the library nodes were then coated with 0.04" and 0.08" of epoxy and the trials repeated and the results showed that the performance was unaffected by the coating. Figures (6) and (7).Reference 3.

Application to theme park inspection.

Theme park rides are made up of several component parts. The structural section of the ride is very similar to the tubulars found in offshore structures with fairly long chord and brace node welds in the track and support areas and thus the problems of inspection are more of access than geometry. Figure (8) The foundation base sections have short fillet welds with access holes similar to those found in offshore sections. Figure (9). These samples were made to examine UK technicians using the ACFM technique to inspect topside production plant. The carriages, axles and carts or trucks have a different problem. Figures (10), (l1) and (12). The majority of the welds on these components are short and have difficult access. This creates two problems one of end effect and the other of weld presentation. To reliably inspect these welds there is a requirement to have small probes with high sensitivity and little response to edge effect and hard wearing probe faces. The communications rate between the ACFM instrument and the computer needs to be fast to obtain a meaningful length of weld on the screen of the computer. The alternative is to scan slowly.

Technical Software Consultants have addressed these problems with the introduction of the mini and micro pencil probes. Both of these probes have either straight or 90-degree access and have stainless steel probe faces. The mini and micro probes have slightly different sensitivity in that one can detect defects 0.04" deep and the other 0.02" These probes are particularly suited for the detection of shallow defects in tight access areas.
A new range of control software QFM 2 has also been produced which has additional features such as a faster communications rate allowing scanning speeds of up to 2"/ second. This can be used for scanning long welds faster or producing longer images on the computer screen for short weld inspection. This software also allows automatic centralisation of the data display and the ability to select and print single scans of data. Different values of lift off can also be selected in order to inspect through different thicknesses of coating.

The combination of these developments will allow the experience gained from critical offshore inspection to be applied to the inspection of the theme park components so that they can be carried out more efficiently and reliably.

In one theme park the track of one of the rides is made up of 300 ties each one having 70 welds of varying length and geometry. During the annual shutdown of this ride a number of these ties are cleaned, inspected using magnetic particle inspection techniques and then the ties are repainted. This normally takes three weeks, one for the cleaning, one for the inspection and one for refurbishment and repainting. This is one of the major problems as the paint has to be matched as closely as possible with the original colours. During one inspection 30 ties were inspected with magnetic particle inspection. During the next inspection the ACFM technique was used. No prior cleaning was required and 64 ties were inspected in four days and one day was used for repairs and re-inspection. No additional painting was required except for the localised painting where the repairs had taken place. In an industry where the customer expects all of the rides to be available when they visit the theme park the reduction in down time is very important.

Highway related inspection.

There are 240,000 welded steel bridges in the USA with an average age of 45 years and of these there are 58.9%, which are structurally defective. The major form of failure in these bridges is fatigue. Reference (4) In 1967 one steel bridge collapsed and 49 people were killed. The initial failure was a 1/8th long fatigue crack in an eye bar. A second bridge failed in 1980, which was also caused by fatigue. In the USA there are 27,000 bridges classed as fracture critical and because of this there is a need to have an efficient and reliable NDT technique. In the opinion of the Federal Highways Authority NDT is still not used efficiently during operations and maintenance. Reference (5) In the UK there are similar problems with the increasing use of heavy road transport and the Euro regulations allowing heavier axle weight. The combination has caused not only fatigue problems but also bridge deck problems.

There are a number of road bridges produced from box girder construction which have longitudinal as well as transverse cracking. Unfortunately the majority of these welds are coated and to clean and inspect would be very expensive and labour intensive. These box sections are about 40' long with both horizontal and vertical welds present. Figure (13) The problem of inspecting for and detecting fatigue cracks through coatings has been well known in the offshore industry for over thirty years and is now being tackled with the use of electro magnetic techniques such as the ACFM technique. The results obtained following inspection are a major factor in calculating the structural integrity of these welds and determining the valid life of the welded joint in terms of Probability of Failure and Reliability Index. The offshore industry required a technique, which could inspect and detect surface breaking fatigue cracks through coatings. Several of these companies funded the development of the ACFM technique and also the trials, which proved its reliability to not only, detect but also to be able to characterise cracks in terms of length and depth. The technique has since been approved by certifying authorities such as Det Norske Veritas, Bureau Veritas, OCB, Germanischer Lloyds and Lloyds Register.

The problems of inspection of road bridges are not unrelated to that of the inspection of offshore structures in that the material is steel which is coated, the welds have difficult access and geometry and the inspection has to be reliable and repeatable. These were the same problems and background with which ACFM technique was presented. The ACFM technique has since successfully overcome these problems using the portable unit, two man rope access, specially developed probes and communication techniques and has been used to carry out inspection of coated steel structures such as offshore structures and bridge sections.

One other problem which has arisen is the failure of overhead signs and light supports which have been subject to high cycle fatigue. This has caused fatalities in one county in the UK and also in one of the Northern States of the USA and has caused the inspection and design of these structures to be re-examined. Some of these designs such as the flagpole design where the weld is on the elbow may have to be changed. Because of their location it is not easy to remove the protective coating inspect and re-coat without causing some disruption to the traffic flow. The use of the ACFM technique would eleviate some of these problems. Figure (14) shows one overhead sign, which still has the white background paint, used during magnetic particle inspection present. One side of this highway was closed to allow inspection to take place. Comparative trials has shown that there can be a 60% saving in time and cost when changing from magnetic particle inspection to a non contacting technique such as ACFM.

Building Construction.

In a recent issue of the Los Angeles Times the front page headlines was " Weld metal tests stir steel building concern" and the leading sentence was "Engineers do not allow this material to be used for building bridges or oil pipelines. Reference (6) They know it's not strong enough." The basis of the story was that trials had been carried out on welds manufactured from a well-known weld electrode and they had produced low fracture toughness values. The impact values were only 5 foot-pounds at 0 degrees Fahrenheit whereas for the majority of structural uses fracture toughness values of 20 foot-pounds at 0 degrees Fahrenheit are required. Reference (7) In the UK even structural material classed as "mild steel" has toughness values of 30 foot-pounds at 0 degrees Fahrenheit. Reference (8) The worrying part of the story was that this material is and has been used for the construction of buildings throughout the West Coast of America. The weld metal is used to join beams and columns used in major constructions and following an earthquake in 1994 it was found that there were ruptured weld connections in 150 buildings, which had been constructed using this weld metal. Building officials in Los Angeles banned the use of this material in July of 1996 for all new construction but there are 1500 steel structures in the area, which have been constructed using this material. The whole of the West Coast is known for its susceptibility to earthquakes and a lot of the area has been subject to tremors at some time or another. It could be quite easy to assume that as the majority of buildings were constructed from this low toughness material they could now include defective welded connections. The scenario for the buildings that have suffered cracking has been that the cracks have initiated in the weld metal during a tremor then have propagated into the adjoining beams and columns. The stress levels, produced by the earthquakes, that these welds would be subjected too would be much higher than those at which the above fracture toughness tests were carried out suggesting even more that this steel would perform inadequately during a seismic shock resulting in cracking of varying severity.

Two points have been made by several engineers in discussions about this potential problem. One is the problem of retrospectively carrying out inspection because the majority of the buildings are covered by claddings of some sort and the other is the level of inspection that was carried out and the level of inspection that should be carried out.
It is accepted that all of the external cladding of a building cannot be removed for inspection purposes but one possibility is to expose areas where it is possible such as on internal walls and utility areas and carry out a percentage inspection which will give an indication of the integrity of the overall structure. The beams, columns and welds will have been coated with a protective paint to deter the onset of corrosion and the inspection technique chosen will have to have a proven track record in the detection of cracking through coatings. The ACFM technique has been used in trials where samples have been coated in epoxy coatings as stated earlier. The technique was able to detect and size in terms of length and depth the defects beneath the coatings. The ACFM technique has a proven track record for its use in the offshore, oil petrochemical and structural steelwork industries as a detection and sizing tool and could be usefully deployed for this application. Any cracks produced during past tremors could now be propagating because of the fatigue process until critical lengths and depths are reached when failure would occur. The ACFM technique could be used to detect and size these

cracks and then the structural engineers could calculate the integrity of the welded joint as they now do on offshore structures. Depending on the outcome of these calculations decisions could be made whether to repair, strengthen or monitor the welded connection. This could prove an economic solution to a possible potential problem.

Comments

Theme park inspection with the emphasis on safety of personnel and integrity of inspection requires a technique that can reliably detect defects and size them through coatings of various types. Trials carried out in the past have shown that the ACFM technique can detect and size defects as well and better than conventional surface breaking detection techniques and its performance will not deteriorate when inspecting through paint or other forms of coating. Therefore with the added benefit of not requiring paint removal or refurbishment the application of ACFM should provide an economic benefit to the inspection of theme parks.

The same arguments can be used for the inspection of road bridges and overhead traffic signs and large light fittings. With the susceptibility of certain constructional steels used in the production of high rise buildings producing cracks at low levels of stress there has been an increasing interest in the use of a least disruptive inspection technique to be used to determine the integrity of major construction welds. ACFM is a non-contacting technique, which can be used to inspect through coatings and can be used to inspect for and characterise any cracks located. These results can then be used to calculate the structural integrity of the welds being inspected and determine their fitness for purpose.

References

1. W. D. Dover, J.R.Rudlin Results of Probability of Detection Trials {Uncoated Welds} IOCE Conference Proceedings 1992.
2. W. D. Dover, J.R.Rudlin. Crack Sizing Trials. IOCE Conference Proceedings 1992.
3. G.A.Raine, W.D.Dover, J.R.Rudlin. Trials on Coated Nodes. IOCE Proceedings 1992
4. Inspection of steel bridges-C Frank University of Texas April 1992
5. The role of Nondestructive Evaluation in Managing our Aging Highway Infrastructure. S Chase. Plenary Address 1997 ASNT Spring Conference Houston March 1997.
6. Los Angeles Times D Willman December 30th1966
7. University of Texas May M D Englehardt May 1994
8. BS 7191 Mild steel for offshore structural use.