THE ALTERNATING CURRENT FIELD MEASUREMENT (ACFM) CRACK DETECTION AND SIZING TECHNIQUE AND ITS APPLICATION TO IN-SERVICE INSPECTION.

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INTRODUCTION

The Alternating Current Field Measurement (ACFM) technique had been used primarily for the detection of fatigue cracks in offshore structures both on the subsea and topside structural sections. The inspection applications were then extended to the inspection of pressurised systems and process plant i.e. pressure vessels and pipe work. Evaluation trials have been carried out to prove the detection and sizing capabilities of the technique compared to the results obtained using more conventional techniques such as magnetic particle inspection, eddy current and ultrasonic creep wave. The technique was then used on the inspection of non-magnetic materials such as stainless steel and titanium and proved equally successful. Since then ACFM has played a useful role in the inspection for non-fatigue cracks at normal and elevated temperatures. Procedures have been produced so that transverse defects can be differentiated from longitudinal defects and cracks detected on the inner surface from the outer surface can be easily identified (only on certain materials and within a specific thickness range).

THE ALTERNATING CURRENT FIELD MEASUREMENT (ACFM) TECHNIQUE

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. The probe is scanned longitudinally along the weld with the front of the probe parallel and adjacent to the weld toe. 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. This gives an 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. 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 above is satisfactory for longitudinal defects and those not orientated more than 45 ° from the weld toe. The effect is different with transverse cracks. Because there is a break in the surface, albeit small and acting as a finite crack it has a similar effect to that of magnetic flux leakage on magnetic particle inspection. The sensors pass over the transverse crack and it affects the Bz enough to produce a sharp Bz pair. The Bx indication produced is opposite to that normally expected from a crack, in that the Bx is positive above the background level producing a sharp indication. This form of presentation enables the detection of longitudinal and transverse cracks to be carried out in one continuous scan. Once the transverse cracks have been detected then it is possible to size them by turning the probe through 90° and carrying out the sizing operation in the standard manner. If a material with a thick skin effect is being scanned then the Bx and Bz can also appear in a modified form. If the skin effect has approximately the same value as the material thickness then it is possible to detect defects on the inner surface from the external surface. In this case the AC field is inverted around the inner surface defect and the Bx then moves upwards but unlike the appearance of the transverse defect the Bx inverted indication will be present for the length of the defect. The Butterfly plot will also be inverted but will be wider than those produced for transverse defects.

Thus by interpreting the data produced it is possible to determine if the defect is longitudinal, transverse or from the inner surface depending upon the material being inspected. These factors have helped to make the technique versatile and applicable to the inspection of petrochemical and process plant.

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.

IN-SERVICE INSPECTION

In-service inspection can include many different areas of activity including the offshore industry, public safety, petrochemical, civil and mechanical engineering. All of these sectors have their unique problems in the forms of access, different forms of coating, from the protective to the cosmetic and the type of materials which require inspection. In the majority of cases fatigue type cracks need to be detected, these are common in the offshore industry and the civil, mechanical engineering and public safety sectors. In the petrochemical industry environmental cracks such as stress corrosion cracking, hydrogen sulphide cracking and stress orientated hydrogen cracks are required to be detected.

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. 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.

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 topside inspection engineers also adopted the technique for the inspection of process and pressurised plant, 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°C and up to 500°C.

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.

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. The foundation base sections have short fillet welds with access holes similar to those found in offshore sections. Samples were made to examine UK technicians using the ACFM technique to inspect topside production plant and were found to have similar geometry to that found in the production of roller coasters. The carriages, axles and carts or trucks have a different problem. The majority of the welds on these components is short and has 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" per second which 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. The ACFM technique has now being used in a number of theme parks and a mechanised system has been installed in one park where more than 1000 supports require inspection. Using the new system the inspection time/ support has been reduced from 8 minutes to 3minutes.

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 (1) 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 (2) 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. 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 electromagnetic 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 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 has 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. 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.

INSPECTION OF DUPLEX AND SUPER DUPLEX MATERIAL

Duplex and super duplex stainless steel has been developed to combine the high mechanical strength of carbon steels with the corrosion resistance of conventional stainless steels. In situations where corrosion resistance is required, they allow the use of thinner section components than before, thus giving great weight and cost reductions. Duplex steels are being increasingly used for process and production pipework operating at high temperatures and pressures. Although the fatigue crack propagation rate is similar to carbon steel the reduced stiffness gives higher fatigue loading and this combined with the thinner walls gives a reduced fatigue life. This makes the detection of fatigue cracking at an early stage more important. The complex metallurgical structure of duplex steels produces problems with most NDT techniques. The complex structure is produced because duplex can occur as islands of ferrite in an austenite matrix or vice versa. If it is the former the material will perform as if it was an austenitic material and the current flow would penetrate several millimetres. If the structure were of austenite islands in a ferrite matrix then the penetration would be only a fraction of a millimetre. The ACFM technique performs equally as well under both conditions but has the added advantage that in the austenitic situation the technique has detected internal defects and defects occurring on the inner surface. When inspecting ferrite based duplex it was found that the depth-sizing model was quite accurate but with the austenite based duplex a 10% inaccuracy was detected. This was overcome by multiplying the value determined by a compensation factor. So far over 15000 welds have been examined using the ACFM technique with a good detection rate and a low number of false calls. New procedures are being developed using higher frequencies to allow discrimination between surface and subsurface defects.

PRESSURE VESSEL INSPECTION:

INSPECTION FOR TRANSVERSE CRACKS IN A PRESSURE VESSEL SHELL PLATE

A section of 1” shell plate which had a ¾” wide weld running across it was presented for inspection. A micro ACFM inspection probe was used to scan the toe of the weld using the normal scanning procedure. Several positive Bx indications were noted indicating the presence of transverse cracking. The probe was then used to scan along the centre of the weld cap from one end of the section to the other. During this scan nine strong transverse crack indications were noted. Their locations were noted along the length of the weld. Two more indications were also noted, one was located at 45° between defects 5 and 6 and this was located during the longitudinal weld toe scan and gave a weak indication. A second indication was noted between defects 4 and 5 also during the toe scan but this was only 4mm long (also transverse) and thus was not covered by the weld cap centre line scan. The defects were then sized using the normal ACFM procedure to produce length and depth information.

COKE DRUM INSPECTION

These drums are subject to thermal and mechanical fatigue due to the process of producing fine grade carbon then using drills to release the final product. Cracking occurs at the bottom section of these vessels but detection is difficult because of the very rough surface. The oil company involved normally allocated two weeks down time for the inspection of six drums using conventional inspection techniques such as magnetic particle inspection and manual ultrasonic inspection. One total inspection of a drum took eight hours with the ACFM technique and the results were compared with the other techniques and gave a good correlation. The oil company has specified the ACFM technique for the inspection of these drums and it is estimated that the total inspection will take four days. The ACFM technique is going to be used to detect and then monitor the crack growth during the life cycle of the coke drums.

DETERMINATION OF PRESSURE VESSEL LIFE

A number of pressure vessels were nearing the end of their determined life but the plant operator wanted to extend the operational life. Inspection of the internal welds had been carried out from the external surface with an ultrasonic technique and detects had been detected. The ACFM technique was then used from the inside to confirm the presence and determine the extent of the internal cracking. The technique was able to measure the length and the depth of the defects and from these measurements it was possible to determine the structural integrity of the vessels and allow them to remain in service. The ACFM technique is now used as the front line and verification inspection technique.

INSPECTION OF DAMAGED AREA OF A REFINERY

A reactor located in a refinery in Minnesota had been damaged in a fire. Following conventional inspection ten defects were located but because of access problems it was not possible to examine them with manual ultrasonic techniques to determine their depth. In subzero temperatures the ACFM crack microgauge and a micro pencil probe was used to determine the depths of the defects. The only problem the inspector had with this inspection was that because the temperatures were so low the screen of the laptop froze.

REACTOR CATALYST BED SUPPORT

The catalyst bed support consisted of a 3” internal strip running around the total circumference of the vessel. Internal diameter cracks were suspected. The ACFM technique was used and only cracks at the toes of the welds were detected. These were sized and run or repair decisions were based on these results.

REACTOR INSPECTION

These particular reactors had a number of nozzles, which were known to be subject to thermal and mechanical fatigue. Plates had been fabricated to reinforce these nozzles and these required regular inspection during the operating process. The external welds were inspected with the ACFM technique and all cracks detected were sized.

ENVIRONMENTAL CRACK DETECTION:

CRACKING IN DISTILLATION TOWERS

The distillation towers were manufactured from carbon steel and the internal surface was subject to a hydrogen sulphide atmosphere producing environmental cracking. The surface was very difficult to clean and the inspection was carried out using the ACFM technique to detect the onset of cracking and to determine the degree of damage by measuring the depth of the cracks.

ABSORBER TOWER INSPECTION

The absorber towers in gas plants are manufactured from thick wall carbon steel. Due to the production process they are subject to hydrogen induced cracking on the tray support welds on the internal surfaces. These welds were inspected and crack depths measured.

RING TYPE JOINT FLANGES

These particular flanges were manufactured from 2¼%Chrome Molybdenum steel which had a weld overlay produced from 347 stainless steel. Stress corrosion cracking was suspected in the weld overlay and decisions had to be made whether to continue operations or repair the cracks.

REFINERY COKE DRUM CRACKING

The coke drum was manufactured from carbon steel and the internal surface was clad in 410 stainless steel. Cracking was occurring in the clad material and the ACFM technique was used to determine the depths of the cracking and to determine if the cracking had extended into the parent material. The ACFM technique was used to detect and measure the size of the cracks in terms of length and depth and a decision was made based on this information whether to repair or monitor.

HIGH TEMPERATURE INSPECTION AND MONITORING OF CRACKS:

RE-CERTIFICATION OF A GAS PROCESS PLANT AT HIGH AND LOW TEMPERATURES

The ACFM technique has found many applications in refineries and process plant, but one of the most successful has been in weld inspection at high and low temperatures. Because the probes do not have an inner core they are not subjected to the Curie point limitations which affect some electromagnetic techniques. The standard probes can be scanned at medium temperatures up to 200°C on process plant and high temperature applications at 500 °C on pressure vessels. The same probes can also be used to inspect plant with surface temperatures of -20 °C. A gas process plant in Scotland was coming to the end of its first year in service and re-certification was required. Because a major part of the plant required inspection the only way that it would be possible to carry out this inspection would be to do some of the inspection prior to and after the shutdown period. This would mean inspecting the plant live at high and low temperatures. A ten-week inspection programme was organised to include the two-week shutdown period. Pressure vessels, separators, saddle welds, girth welds, pipe work and fractionating columns were inspected over this period using the same probe with a 25 metre cable length and a U9 crack microgauge instrument. Six defects were detected and these ranged from 10mm-70mm long x 4mm deep. The operating temperatures of the plant ranged from 225°C to -20°C. Because of access problems it was not possible always to locate the crack microgauge near to the worksite. This problem was overcome by using a 25-metre probe cable from the unit to the probe and a 30-metre cable between the unit and the laptop. The probe operator communicated with the crack microgauge operator using a head-up display system and two-way audio communications. This enabled the inspection of fractionating columns and other high parts of the plant to be inspected without the use of scaffolding. The ability of the technique to be used to inspect through coatings as well as at high and low temperatures meant that critical areas which could not be inspected on line were inspected during the shutdown period and the remainder was inspected on line. During the first inspection ACFM was used as the front line inspection tool with verification of defects being carried out by local coating removal and MPI followed by grinding to remove the defects. Good correlation was found between the techniques and verification is not now carried out and the ACFM technique has been used during every maintenance shutdown period.

STAINLESS STEEL PRESSURE VESSEL

A particular client had a requirement to monitor stainless steel pressure vessels operating at 500°C. It was not possible to shut down the plant so a number of probes were developed to be able to operate continuously at these high temperatures. The probes for inspection were manually deployed whereas the probes for monitoring were continuously mounted on the vessels beneath the lagging and automatically monitored remotely.

PROCESS PIPE WORK

This was another case of crack monitoring. Cracks had been observed in the circumferential welds of a pipeline operating at 750°F and the plant operator did not want to shut down the process plant. Manual ACFM inspection was used to determine the size of the cracks and the fracture mechanics engineer was able to determine the structural integrity of the welds. The plant was allowed to continue operating and the cracks were monitored on a regular basis.

FABRICATION OF PIPE WORK

A new 347 stainless steel pipe line was been fabricated and in the past the process has been to produce the root weld allow the weld to cool down then inspect with dye penetrant. Any repairs were then carried out and the next pass laid down after re-heating. At each inter-pass stage the weld was allowed to cool, then inspected and then reheated to allow welding to continue. The ACFM system together with a pencil probe was used instead of the dye penetrant inspection as a quality control tool. No cooling below the re-heating temperature was required and the weld production increased. The specialised welding time had been reduced from 12 hours /weld to 2 hours /weld because of the reduced inspection time and heat cycle time. No repairs were necessary during the fabrication.

TURBINE DISC INSPECTION

Turbine discs had been removed for inspection. The turbine disc roots required inspection for cracks which is normally carried out using the dye penetrant technique. This only gives detection information. The ACFM technique was used to inspect the disc roots for cracks and was also used to size them. Run or repair decisions were made on each disc based on these results.

FORGING INSPECTION

A large 40Kton forging press produced from cast steel had started to crack due to fatigue. The casting was inspected and all of the cracks were measured. The cracks were removed by grinding and the depths confirmed and repairs were carried out. The repairs were then inspected to confirm that no cracks had been produced during the repair process.

OPTIMISATION OF INSPECTION INTERVALS AND EVALUATION OF THE ACFM TECHNIQUE.

The objective of any inspection technique is to detect defects at their earliest stage of growth. Crack growth has four stages, initiation, stable crack growth, unstable crack growth then failure. The growth rate can be either the most probable growth rate, the worst likely or the worst possible and this can only be determined by monitoring the defect once it has been detected. Once this has then been established the course of action can be decided upon, either to continue monitoring, refurbish or repair. This action can only be taken if the inspection technique has proven reliability in detection and characterisation of the defects.
The monitoring or optimisation of the inspection intervals can also be calculated using typical life prediction curves, which requires the input of inspection results. These life prediction curves describe the reduction in reliability with years in service. This input can then be used to update the results and either maintains the same inspection intervals with increased reliability and reduced probability of failure or maintains the same reliability and probability of failure and increase the inspection intervals.

Once again this technique can only be used if the inspection technique used has a high level of detection reliability and characterisation of defects.

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 (3). 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 geometry’s 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 (4). 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. Reference (5).

COMMENTS.

The ACFM technique's reputation has grown based on initial work carried out by the Department of Mechanical Engineering, University College London in its work on detection and sizing of surface breaking fatigue cracks. This showed that the ACFM technique had a high level of Probability of Detection and characterisation of defect length and depth. This enabled the technique to establish itself in the offshore and mechanical and civil engineering world as well as the petrochemical industry for the detection of surface breaking fatigue cracks. From there it has progressed and shown that it is equally successful in the detection and sizing of environmental cracks. The technique has also been used to inspect non-magnetic materials such a stainless steel and titanium and to inspect through coatings making it a useful and adaptable inspection technique for the new millennium.

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