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FATIGUE CRACK MONITORING FROM INITIATION TO THROUGH CRACKING IN WELDED THICK STEEL SECTIONS (U)

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FATIGUE CRACK MONITORING FROM INITIATION TO THROUGH CRACKING IN WELDED THICK STEEL SECTIONS (U)

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Summary (U)

This report describes the overall Non-Destructive Evaluation (NDE) policy of the Fatigue Section, ARE Dunfermline, with respect to the fatigue testing of internally stiffened welded steel structures. These structures, of thick section high yield strength steels, are subjected to high external cyclic pressures in a water environment. The report covers the application of various non-destructive testing (NDT) techniques (Visual, MPI, Eddy Current, ACPD, Ultrasonic ToFD and conventional Pulse-Echo Ultrasonics) in the areas of weld assessment, fatigue crack initiation detection, fatigue crack sizing and fatigue crack growth monitoring. Data is presented on the size of initiating cracks expected to be detected and on the accuracy of the sizing and monitoring techniques used.

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FATIGUE CRACK MONITORING FROM INITIATION TO THROUGH CRACKING IN WELDED THICK STEEL SECTIONS (U)

1. INTRODUCTION

The Fatigue Section of the Admiralty Research Establishment (ARE), Dunfermline, conduct fatigue tests on large welded steel structures (models). These are constructed from thick section (>25 mm) high yield (HY) strength naval steels. They are generally internally stiffened with the stiffener(s) being attached to the shell (pressure hull) by full penetration T-butt welds. The fatigue tests consist of subjecting the model to high cyclic external pressures, in a water environment, until fatigue cracks propagate either completely through the pressure hull material or to a specific crack depth.

To obtain fatigue data, particularly the onset of crack initiation, the crack growth rate and the through crack life, it is essential that reliable non-destructive testing (NDT) is carried out. During the past decade ARE(D) has continually improved its capabilities in this field by running concurrent, intra- and extra-mural research and development projects. Some notable examples are the Alternating Current Potential Drop (ACPD) and the Ultrasonic Time of Flight Diffraction (ToFD) techniques.

This report lays out the overall non-destructive evaluation (NDE) policy for current and future large scale fatigue model programmes. It details the areas of application for the various NDT techniques and highlights areas for further intra- or extra-mural research and development.

2. PREPARATION

To aid the NDT operator(s), Reference Lines are painted (white) on the model's pressure hull as described below:-

2.1 Axially

All cylindrical portions of the model have lines painted every 15 degrees, from the crown reference point in a clockwise direction looking forward, on both the external and internal surfaces. Lines are identified with their relevant degree markings near to the forward and aft domes, both externally and internally.

2.2 Circumferentially

Lines depicting the extremities of the stiffener to pressure hull T-butt weld are painted over the full circumference on the external surface, for all stiffeners (Frames).

Lines depicting the extremities of circumferential pressure hull butt welds are painted over the full circumference, externally and internally, for all dressed butt welds. Where only one side is dressed this side is painted.

Painting of the NDT Reference Lines is one of the final production tasks carried out on a model.

On completion of the model's static pressure test all non-essential internal strain gauge installations and cabling are removed and areas of bare metal protected by paint. At every 5 degrees along the circumference of each weld under test, areas are prepared for the ACPD inspections by removing rust, scale and paint down to bare metal. On models less that 1.4 metres in diameter, this is best done over the full circumference. These areas are protected from corrosion by a peelable, sprayed vinyl coating applied after each ACPD inspection.

On the first removal of the model from the fatigue chamber for external Ultrasonic ToFD inspection, all non-essential external strain gauge installations and cabling are removed. Where this damages large areas of the NDT Reference Lines, these are repainted as per paragraphs 2.1 and 2.2.

3. NDE PROCEDURE

Before fatigue cycling can commence an initial full datum inspection is carried out using the following techniques:-

a. Visual

b. Eddy Current (AMLEC)

c. Manual ACPD

d. Secondary techniques, MPI and Ultrasonics if required

3.1 During Fatigue Testing

The inside of the model is drained and vented periodically, approximately every 2000 cycles, to allow inspection to detect the onset of crack initiation by:-

a. Visual

b. Eddy Current

c. Secondary techniques if required

3.2 Following Crack Initiation

As 3.1 plus the following to size any cracks detected:-

d. Manual ACPD

e. Periodic removal of model for Ultrasonic ToFD

f. Attachment of On-line ACPD monitoring when suitable

3.3 Fatigue Crack Growth

When fatigue crack growth is established, continuous crack growth monitoring is carried out by On-line ACPD with inspections as 3.2 above. The interval between these inspections being gradually increased to approximately 15000 cycles.

4. VISUAL INSPECTION

This is the principal technique, applied internally to check the following items:

a. Cleaning and Dressing

To ensure that all slag has been removed. To note any positions of heavy grinding marks, which may indicate a repaired area. Possible site for early crack initiation or growth from an embedded defect.

b. Contour

To check the weld contour and that the weld surface is regular and of a satisfactory visual appearance. May give some indication as to the weld most likely to initiate cracks first.

c. Weld Width

Measurements of weld throat thickness and leg length are taken at every 15 degrees with the aid of a Welding Institute weld gauge.

d. Undercut

The position of any undercut which is likely to affect later NDT techniques is recorded. Any serious undercut is sized with the Welding Institute weld gauge even if it lies outside a 5 degree monitoring site. Typically undercut provides ideal sites for early crack initiation.

e. Overlap

Any positions of overlap are noted although it is generally not a problem.

f. Weld Flaws

The weld and the heat-affected zones are checked for transverse and longitudinal surface cracking. If surface cracking is detected then the secondary NDT techniques may be used in an attempt to establish the orientation and depth of these flaws prior to fatigue cycling.

To aid this inspection a magnifying eyepiece (x10) is occasionally used.

After the initial datum inspection, further visual inspections are mostly concerned with the condition of the peelable vinyl coating which is used to protect the surfaces after ACPD inspections. This coating has proved to be a valuable aid in determining the extent of the surface length of the crack(s). Under the cyclic loading the mouth of the crack(s) opens sufficiently to snap the vinyl coating thus allowing corrosion. As the vinyl coating is usually dyed (Red or Blue) the corrosion products can be quite easily seen and this has been termed 'Rust Line Indication'.

5. EDDY CURRENT

This is the principal technique applied internally, for the detection of cracking and the determination of the onset of crack initiation. An AMLEC Mk9 instrument with a PRA4 soft cored hand probe is used and readings are taken every 5 degrees around the circumference of the welds under inspection.

Subsequent readings are compared with the previous readings and are plotted on a polar diagram. Fatigue cracking is deemed to have occurred on the second occurence of an increased (>10 AMLEC units) reading at the same location. Figure 1 shows a typical polar plot indicating multiple crack initiation sites. AMLEC inspections are continued until either the readings are off-scale or, because of multiple crack initiation and growth, full ACPD inspections are being carried out.

The data shown in Figure 2 was obtained from a series of tests, carried out on T-butt welded test pieces to ascertain the capabilities of the AMLEC instrument, (1)*. Although it is used purely for detection it can be seen that there is some indication of severity of cracking. However, it is only when the crack depth is greater than 2.5 mm that a 100% confidence level of detection is achieved, as at these depths full scale deflection occurs. Summing the correct calls for crack depths between 0.3 and 2.5 mm, indicates that a confidence level of detection of 83% can be expected for cracks in this range of depths. On dressed butt welds the performance is expected to be better.

( )* References on page 8

6. MANUAL ACPD

This is a principal technique applied internally for crack sizing (path length) and crack growth monitoring, (2). The initial inspection provides a datum for subsequent inspections and sizes any gross undercut or surface breaking flaws detected by the Visual and Eddy Current inspections. Measurements are again taken every 5 degrees around the weld circumference and are inputted into an in-house computer program, 'ADAGE' (3), for analysis and graphical display.

From past experience and numerous tests it is expected, that a nominal depth of 0.75 $\pm$ 0.25 mm will be recorded during a datum inspection of a T-butt weld. It has also been noticed that for indicated crack depths of less than 5 mm the datum value should be deducted to improve the accuracy. It is however expected to achieve an accuracy of $\pm$ 1.5 mm for measured crack depths in the range of 2 to 50 mm. The accuracy for crack growth increment measurements is expected to be within $\pm$ 0.5 mm.

There are a number of physical features which can introduce large errors into the ACPD measurements and these are unfortunately generally not evident during the inspection. For example, crack closure, crack bifurcation, inclusions and Lamellar Tearing. However most of these features can be identified when the Ultrasonic ToFD inspections are carried out. It is also helpful if the inspector appreciates the likely fracture mechanisms at work in the material under test.

7. SECONDARY TECHNIQUES

These techniques are only applied when either the Visual or Eddy Current inspections have detected surface breaking cracks, transverse or circumferential.

7.1 MPI

Magnetic Particle Inspection, utilising either a permanent magnet or an electro-magnetic yoke, with dry powder or wet (visible or fluorescent) inks, may be applied internally or externally to highlight surface breaking cracks for photographic evidence.

7.2 Conventional Ultrasonics

Pulse-echo ultrasonics is generally used to inspect areas of surface cracking where the cracks are transverse or, if circumferential, lie within the body of an undressed weld. Manual or semi-automatic scanning can be used with 0, 45, 60 and 70 degree probes at 5 MHz. Typically A-scan display utilising 6 dB or 20 dB sizing routines, B-scans can be generated in semi-automatic operation.

8. ULTRASONIC ToFD

This is the principal ultrasonic technique applied usually externally although it may be applied internally if called for. It is used via a ZIPSCAN ultrasonic system to size cracks (through thickness), determine the crack growth rate, locate crack tips in space and assess the angle of cracking.

The inspection involves scanning across the weld at every 5 degrees to generate a B-scan display from which the crack is sized, the tip located and the crack angle assessed. This is then followed by scanning circumferentially along the crack tip locations to produce a D-scan showing the crack tip profile.

It is the most accurate technique applied, better than ± 1 mm, and can detect and size surface breaking planer defects originating from the remote surface with depths of 0.3 mm to 0.75t (where t = plate thickness). However, it entails removal of the model from the fatigue chamber, which is labour intensive, along with its associated protracted down-time in the fatigue test. It has been shown, from On-Line ACPD results, that long down-times can affect the fatigue crack propagation rate when cycling is re-commenced. Retardation of the growth rate over a period of up to 500 cycles can occur before the growth rate returns to the same value as prior to the NDE halt. ToFD inspections are therefore not carried out at every NDE halt but are done at selected intervals usually based on the depth of the dominant fatigue crack.

9. ON-LINE ACPD

This is a development of the manual ACPD technique, where the hand probe and magnetic field contacts are replaced with permanent spot welded connections, as described in (5). It is the principal technique for crack growth monitoring and for the determination of through cracking. The technique allows real-time measurement of crack size (path length) and operates via glands in a water environment while subjected to high cyclic pressures. It may be used in semi or fully automatic operation with the readings (operator selectable) usually being taken every 250 cycles. These are triggered so that they are taken under maximum crack opening conditions. The data obtained is analysed and displayed graphically through 'ADAGE'.

The technique can be used to determine the onset of crack initiation, depending on when it is applied. It can also be used to measure the amount of crack closure and to determine the loading conditions to achieve this.

10. FUTURE RESEARCH AND DEVELOPMENT

There are a number of areas where further development will be beneficial, particularly on the application, reliability and reduction of NDT inspection times. It is not expected to greatly improve the accuracy of any of the techniques applied, nor is it expected in the short time-scale to utilise any new NDT techniques.

Recently a combined, minaturised battery powered, Eddy Current and ACPD instrument has been developed and designated 'SAS 01', search and size. This instrument was not conceived as a direct replacement for the AMLEC and ACPD instruments currently in use, rather it was developed to improve the capabilities to inspect in difficult and cramped conditions. As it can be treated as a prototype, there will be some development of both its internal electronics and the external fittings, to improve its reliability and ease of use.

The On-Line ACPD technique holds the key to continuous fatigue testing with fully computerised crack monitoring and analysis. The major problem being the limited number of locations that can be monitored due to the restricted access through the watertight glands. Development of a submersible multiplexing unit, which could withstand the high cyclic pressures, would overcome this. Only a relative small number of communication lines would need to be passed through watertight glands. Early work into this has indicated that it is feasible but more research and testing is required, particularly into the internal electronic components. If a system is successfully developed there would have to be some research and development into the actual style and type of measurement connections to be used with such a unit, as the style currently used is not suited to applications involving hundreds of monitoring sites.

11. CONCLUSIONS

By following the outlined NDE procedure, at any time during the fatigue testing of a model a full picture of the state of fatigue cracking is available. Generally at each stage of fatigue cracking (initiation, growth and through cracking) at least two of the techniques compliment each other and can be used to verify the findings of each other.

Based on the current models, during the crack initiation stage the period of inspection is likely to be at most every 2000 cycles and as the cracks propagate and coalesce this interval will be gradually increased until, with the application of On-Line ACPD monitoring, it is approximately every 15,000 cycles. If for future models the loading conditions and the levels of residual stress are different then the NDT intervals will have to be adjusted to suit the expected fatigue life.

12. RECOMMENDATIONS

It is recommended that:

a. The paragraphs (2.1 and 2.2) containing details on the necessary NDT Reference Lines be incorporated into future Fatigue Model specifications to ensure consistency.

b. During the life of a model Ultrasonic ToFD inspections are carried out at least three times, at dominant crack depths of 'a' = t/4, t/2 and t, where t = pressure hull plate thickness.

c. Further development of the On-Line ACPD be conducted with the aim of developing a submersible system capable of monitoring 144 positions.

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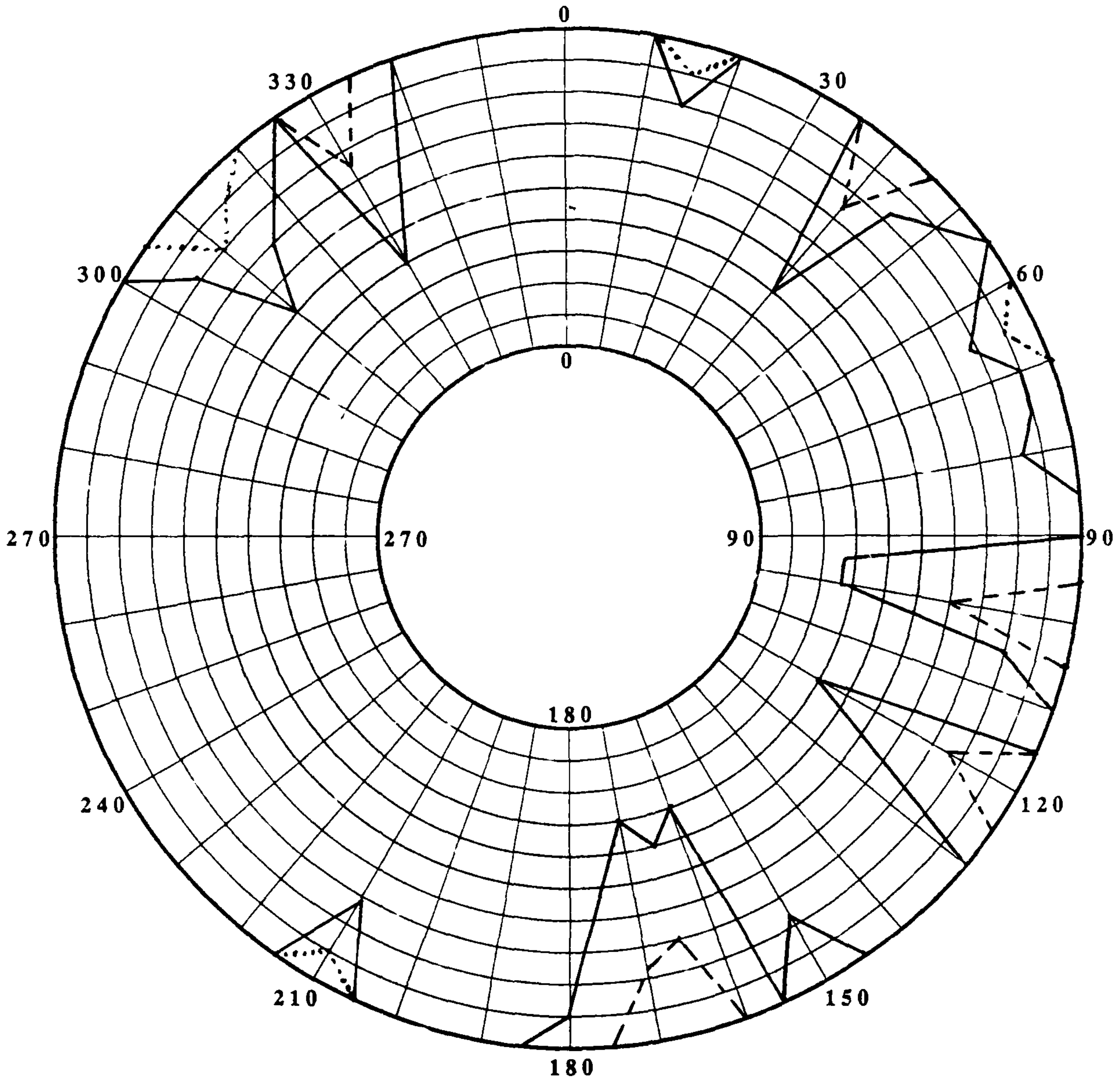

--- 3000 CYCLES; ....5000 CYCLES; —— 7000 CYCLES;

TYPICAL (AMLEC) CRACK INITIATION PLOT

FIGURE 1

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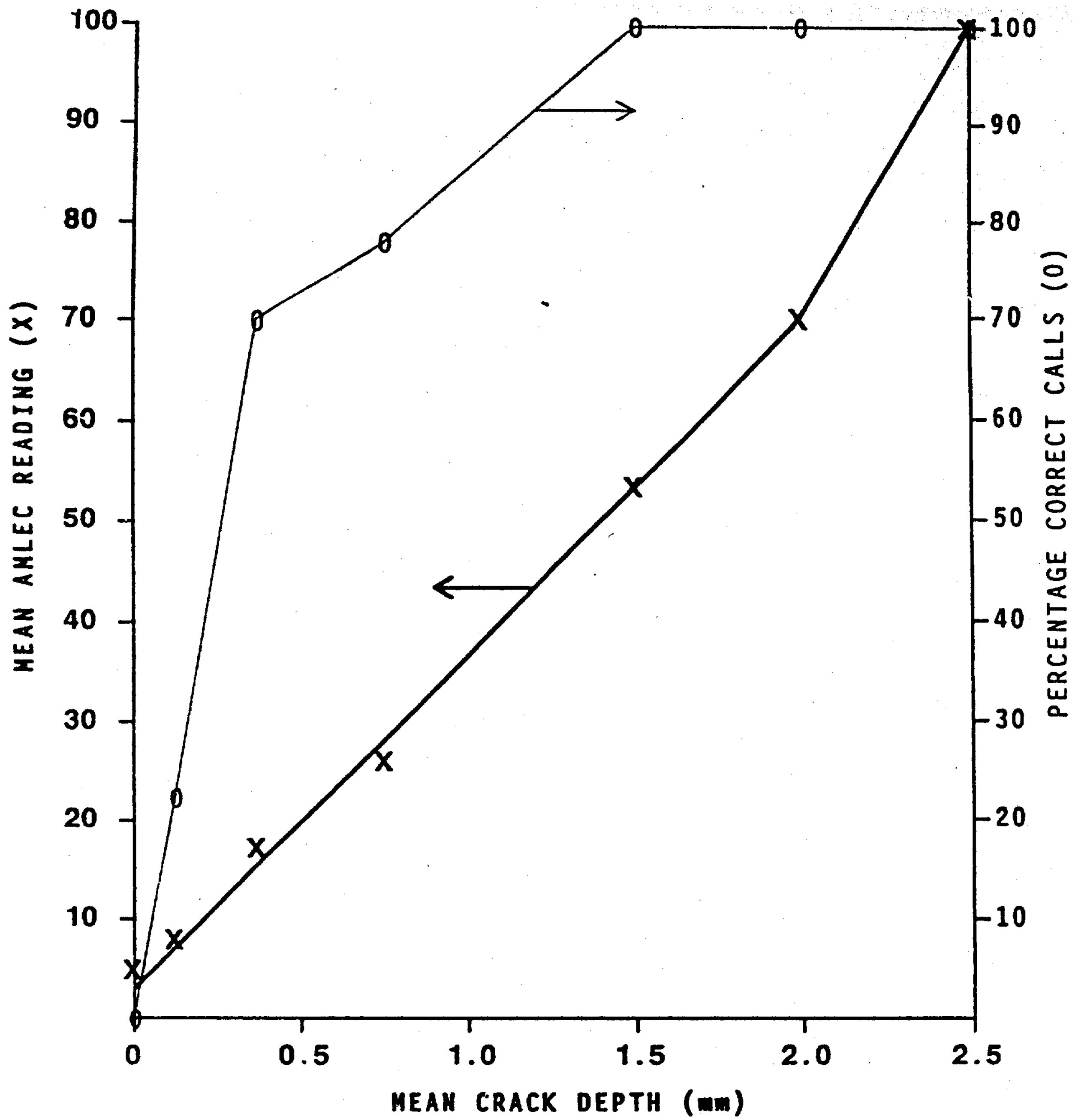

Data obtained from:-

AMTE(S) TIM(UME) 86202, DETECTING FATIGUE

CRACKS IN T-BUTT WELDS, APRIL 1986

DETECTION OF FATIGUE CRACKING IN T-BUTT WELDS BY AMLEC

FIGURE 2

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