Assessment of Corrosion under Insulation and Engineered Temporary Wraps using Pulsed Eddy-Current Techniques

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Abstract

Inspection of Corrosion under Insulation (CUI) and material degradation under Engineered Temporary Wraps (ETW) has proven to be a challenge to reliably detect and monitor using a number of NDT methods. Pulsed eddy-current has recently been identified as a potential NDT method for this application. Importantly, the lift-off between the sensor and the structure being inspected can accommodate the insulation or ETW layer. This work evaluates the effectiveness of current instrumentation to detect and assess the degradation under in-service conditions. Moreover, the components tested and the degradation effects are representative of those found in-service. A comprehensive inspection and recording process has been undertaken and the resultant data analysed to identify operating constraints of the method relative to typical components, representative degradation, dimensions of the degradation and standoff ranges.

1. Introduction

Carbon steel is a widespread construction material used for the offshore structures in the oil and gas industry [1]. Carbon steel is an alloy of carbon and iron containing up to 2 % mass fraction carbon, up to 1.65 % mass fraction manganese, up to 0.60% of silicon and residual quantities of other elements [2].

Offshore installations are subject to corrosive environment and heavy operational conditions including elevated temperatures and loads which impose high requirements on the structural integrity of these structures [3].

External corrosion of carbon steels is determined by the marine atmospheric environment containing water and chloride salts [1]. Corrosion under insulation (CUI) is a significant problem associated with offshore carbon steel structures. Internal corrosion of carbon steel in oil and gas industry is mainly caused by water and dissolved oxygen in the petrochemical products and can have following mechanisms [1, 4]:

- CO$_2$ and H$_2$S corrosion
- Microbiologically induced corrosion
- Sulfide stress cracking (SSC)/stress corrosion cracking (SCC) caused by H$_2$S
- Hydrogen-induced cracking/step-wise cracking (HIC/SWC)
- Alkaline stress corrosion cracking (ASCC).
Traditional methods of NDT used for corrosion monitoring in offshore oil and gas installations encompass visual examination, ultrasonic testing (UT), acoustic emission (AE), radiography, eddy current testing (ECT) and magnetic flux [4].

UT requires preliminary surface preparation and acoustic couplant (often water). UT is not suitable for CUI without removing insulation which is a costly operation. Corrosion reactions generate elastic waves which can be detected by AE sensors. The main disadvantage of AE technique is that offshore environment is generally noisy and the AE signals are weak resulting in poor signal-to-noise ratio. Radiography is only suitable for limited pipe diameters and involves ionising radiation hazardous for the inspectors. MFL is efficient when deployed from inside a pipe. Sensitivity of MFL quickly decreases at large standoffs determined by the insulation when testing from outside a pipe/vessel.

ECT is a non-contact electromagnetic NDT technique based on induction of eddy currents in an electrically conducting test piece by means of an excitation coil and detection of the EC response either by any suitable sensor(s), as shown in Figure 1 [5]. Pulsed Eddy Current (PEC) is an electromagnetic technique using rectangular magnetic field excitation (see Figure 2a) which induces eddy currents in the steel wall [6, 7]. NDT of ferromagnetic metallic components by means of PEC is regulated by BS ISO 20669:2017 [5]. Insulation and weather jacket constitute coating [5].

![Figure 1. Eddy currents testing of a component under coating [5]: 1 sender coil, 2 receiver devices, 3 primary magnetic field, 4 secondary magnetic field, 5 eddy currents, 6 cover/sheeting, 7 insulation, 8 tested component](image)

The eddy currents pulse diffuses into the test specimen until it reaches the far surface. Secondary magnetic field of eddy currents is acquired by the receiver device of the PEC probe [8]. The moment in time when the EC first reach the far surface is indicated by a sharp decrease in the received PEC signal shown in Figure 2b [6]. Beginning of the sharp decrease (bending point) is the measure of wall thickness. PEC is highly efficient for evaluation of corrosion under coatings [9] and is being to monitor wall thickness of offshore steel structures [10].
This paper presents results of evaluation of wall thickness of carbon steel pipes with internal corrosion and external corrosion under insulation by means of state-of-art PEC instrumentation. A comprehensive inspection and recording process has been undertaken and the resultant data analysed to identify operating constraints of the method relative to typical components, representative degradation, dimensions of the degradation and standoff ranges.

![Figure 2. (a) PEC excitation signal; (b) PEC response signal](image)

2. Methodology

2.1 Samples

The following carbon steel samples were examined in this study:

1) TRAC Sample 1, a Blistered Pipe, shown in Figure 3 which illustrates extension of CUI in this sample without insulation and aluminium weather jacket which were applied during testing:
   - Outer diameter: 331.0 mm
   - Nominal wall thickness: 10.5 mm
   - Insulation: 50.0 mm
   - Weather Jacket: Aluminum 1.0 mm
   - Corrosion type: external CUI

2) TRAC Sample 2, Epoxy Coated, Figure 4:
   - Outer diameter: 200.0 mm
   - Nominal wall thickness: 10.5 mm
   - Coating: epoxy 5.0 mm
   - Corrosion type: internal

3) Pipe with drilled holes:
   - Outer diameter: 160.0 mm
   - Nominal wall thickness: 8.0 mm
   - Artificial defects: through holes with diameters of 25mm and 50mm
2.2 Experimental setup

The following commercial PEC instrumentation was used in this study: eddyfi Lyft and Maxwell NDT. Figure 5 shows the used PEC instrumentation: (a) eddyfi Lyft with various probes, (b) Lyft probe PEC-089-G2-HT05S, (c) Maxwell NDT PECT, (d) Maxwell NDT small probe P1 and medium probe P2. Properties of the LYFT probe were as follows:

- Model: PEC-089-G2-HT05S
- Probe Footprint: 95.2 mm
- Circumferential Footprint: 124.5 mm

Properties of Maxwell NDT probes are given in Table 1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Nominal lift-off range, mm</th>
<th>Nominal footprint, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 (small)</td>
<td>0 – 20</td>
<td>60</td>
</tr>
<tr>
<td>P2 (medium)</td>
<td>20 – 50</td>
<td>120</td>
</tr>
</tbody>
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2.3 Thickness Measurement Approach

Coordinate grids were applied to sections of the tested samples. C-scans (2D surface images) of each section were acquired in grid-mapping mode using both eddyfi Lyft PEC-089-G2-HT05S probe and Maxwell PECT with an appropriate probe depending on the nominal wall thickness and standoff. Standoff was varied either by placing coating (combination of insulation and weather jacket) upon the sample or using plastic spacers.

3. Results and discussion

3.1 Eddyfi Lyft

Figure 6 shows C-scan acquired using Eddyfi Lyft on the TRAC Sample 1 with insulation and weather jacket.
Figure 6. Eddyfi Lyft: TRAC Sample 1 with insulation and weather jacket

3.2 Maxwell PECT

Figure 7 shows C-scan acquired using Maxwell PECT & medium probe P2 on the TRAC Sample 1 with insulation and weather jacket. It shows a good qualitative agreement with Eddyfi Lyft results. Average deviation between Maxwell and Eddyfi Lyft results is 0.23mm, maximum deviation being 0.75mm. Figure 8 shows C-scan acquired using Maxwell PECT & medium probe P2 on the TRAC Sample 1 with insulation without weather jacket. Average deviation between results for the TRAC Sample 1 with insulation and with and without weather jacket acquired with Maxwell PECT is 0.10mm.

Figure 7. TRAC Sample 1 with insulation and weather jacket

Figure 8. TRAC Sample 1 with insulation without weather jacket
An individual blister located on the TRAC Sample 1 was scanned both in contact and through coating (insulation and weather jacket) with corrosion products (scab) of thickness above 5mm present and after corrosion products were mechanically removed. Figure 9 shows C-scan of the individual blister without corrosion product (scab) in contact (no coating) acquired using small probe P1. Figure 10 shows C-scan of the individual blister without corrosion product (scab) through insulation and weather jacket acquired using medium probe P2. Average deviation with respect to the contact measurements is 0.31mm, maximum deviation being. This result demonstrates that presence of coating within the operating range of PEC equipment does not significantly influence results. Figure 11 shows C-scan of the individual blister with corrosion product (scab) through insulation and weather jacket acquired using medium probe P2. Average deviation with respect to the case of no corrosion product is 0.36mm, maximum deviation being 0.57mm. This result demonstrates that moderate amount of corrosion product does not significantly influence results.

Figure 12 shows C-scan acquired in contact using P1 probe on the Enquest sample with internal corrosion and erosion channel.

Figure 13 shows C-scan acquired in contact using small P1 probe on the sample with a hole of 25mm diameter. The PEC signature of a hole is clearly detectable although the thickness readings in the centre of the hole are higher than 0mm due to EC response averaging effect over the probe footprint. Figure 14 shows C-scan acquired at standoff of 20mm using small P1 probe on the sample with a hole of 25mm diameter. Thickness readings in the centre of the hole are higher compared to the contact measurement (see Figure 13) since the effective footprint of the probe increases with standoff as 1.5 x
Figure 11. Individual blister with corrosion product (scab) through insulation and weather jacket.

Figure 12. Enquest sample with internal corrosion and erosion channel.

Figure 13 Hole Ø25mm in contact.

Figure 14 Hole Ø25mm at 20mm standoff.

(Standoff + Wall Thickness). Figure 15 shows C-scan acquired at standoff of 20mm using small P1 probe on the sample with a hole of 50mm diameter. As expected, thickness readings in the centre of the larger hole are lower than that in case of the 25mm hole (Figure 14) since the average “weight” of the no-metal signal is higher for the bigger hole.
3. Conclusions

This work presented results of PEC NDT to detect and evaluate corrosion in offshore carbon steel structures. The components tested and the degradation effects are representative of those found in-service. A comprehensive inspection and recording process has been undertaken and the resultant data analysed to identify operating constraints of the method relative to typical components, representative degradation, dimensions of the degradation and standoff ranges.

- Wall thickness was measured through insulation of 50mm and aluminium weather jacket in walls of thickness up to 20mm with accuracy of 0.25mm;
- Thin aluminium weather jacket has virtually no impact on results;
- Standoff increases the area over which thickness is averaged;
- Larger probe footprint increases the area over which wall thickness is averaged;
- Corrosion products (ferromagnetic scab) of thickness of up to 10mm has similar influence on the PEC response as standoff;
- Holes in walls of thickness of 8mm produce an indication in C-scan when scanned with medium (P2) probe at stand-off distance of up to 20mm.

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References


