Development, Validation and Execution of the Automated Ultrasonic Testing of a Subsea Pipeline Hot Tap Weld

Malcolm MILLER
Shell U.K. Limited
1 Altens Farm Road, Nigg, Aberdeen, AB12 3FY, United Kingdom
Tel: +44 1224 882569
E-mail: malcolm.miller@shell.com Web: http://www.shell.com/eandp

Abstract

As part of a project to supply gas to Britain from Norway in 2007, there was a requirement to build a new gas export pipeline and connect it into an existing high-pressure gas transportation pipeline. This connection was made by means of a 16-inch hot-tap into a 36-inch line i.e. welding a 16-inch stub on to a 36-inch pipe while the pipe is live carrying gas. The additional challenge was that the location of this work was 400km offshore in the North Sea and at 140m water depth. Due to the nature of the work, there was a major risk to safety and the environment; therefore it was vital that the connection was welded and tested to extremely high standards. The ENIQ methodology (European Network for Inspection and Qualification) was used to enable a rigorous and structured approach to be adopted.

A high sensitivity automated ultrasonic inspection was developed and qualified such that there was extreme confidence that a reliable test could be performed. Following this exercise the hot tap weld was satisfactorily inspected and the whole project completed without concern.

Keywords: automated ultrasonic inspection; ENIQ; hot-tap

1. Background

The 23 kilometre-long Tampen Link pipeline between the Statfjord field and the British sector of the North Sea provides transportation capacity for gas from the Statfjord late life project. The Tampen Link has a diameter of 32 inches. The Tampen Link ties in the Statfjord field with the 36-inch diameter FLAGS pipeline that runs from the Brent field in the British sector to St. Fergus in Scotland. This link is “tied in” by means of a 16 inch hot tap into the 36-inch FLAGS line (hot tapping is a means of adding a branch connection to an existing pipe without a shutdown of service in the main pipe) i.e. welding a 16-inch stub on to a 36-inch pipe whilst carrying high pressure gas. This task was significantly more complicated due to the location of the link 120 miles offshore and in water depth of 140 metres, as indicated in Figure 1.
2. Risk and Benefit

Working on such a live line presents major risks: safety of the team working on the job, or the consequence of uncontrolled release of the high pressure, flammable gas; environmental due to release of large quantity of hydrocarbon into the sea; financial - if there was damage to the pipeline which is a major link in the gas supply chain to UK. However the benefit is that it secures a substantial supply of gas to UK mainland for the next 20 – 30 years.

Thus it was absolutely critical that the tie-in weld be constructed and inspected to the highest standards possible. At an early stage of the project there were three significant decisions about the NDT methodology:

1. The ultrasonic testing should be carried out in an automated manner with full data capture and analysis capability
2. An Engineering Critical Assessment (ECA) approach would be adopted for consideration of any indications detected, although the testing would still be compliant with the codes DNV-OS- F101\(^1\) and EN 1714\(^2\)
3. The ENIQ\(^3\) approach to qualification of inspection techniques and procedures would be adopted

3. ENIQ Methodology

The ENIQ methodology has two essential elements:

1. A statement of requirements specific to the inspection concerned; this is termed the “Input Data”;
2. The appointment of an independent “qualification body” to oversee the qualification process and to certify that the inspection is qualified against the input data once the qualification process has been completed to their satisfaction.

Normally, the qualification process addresses each of the three main elements contributing to the inspection, namely the procedures, the equipment and the personnel.
The ENIQ methodology also “strongly recommends” the use of “Technical Justification”. The Technical Justification is a document that presents a reasoned argument as to why the inspection is expected to meet the requirements defined in the Input Data. This reasoned argument may be supported by mathematical modelling. In addition, the methodology envisages that the qualification process will usually include a practical demonstration of the effectiveness of the inspection on testpieces simulating the component to be inspected and incorporating artificially introduced defects which relate to the Input Data.

Thus, for this project, the qualification methodology covered:

- Design & development of the inspection techniques
- Selection and provision of the inspection equipment
- Production of the inspection procedure
- Mathematical modelling
- Design of an Open Trials testpiece
- Provision of a justification for the open trials testpiece design
- Conduct and reporting of Open Trials
- Production of a Technical Justification
- Training of inspection operators in the weld inspection
- Qualification of inspection

4. Inspection Organisation

The prime contractor for the whole project was Acergy, supplying the Diving Support Vessel (DSV) and all welding facilities and diver NDT technicians. Sonomatic, formerly known as Veritec, supplied UT modelling, CAD ray tracing, mechanical and sample design, qualification trials and execution of all of the automated ultrasonic testing (AUT) services. Shell Global Solutions International, Amsterdam, acted as the independent inspection qualification consultant. Whilst Acergy and Sonomatic had worked together on a previous sub-sea hot tap, this project posed novel challenges and more demanding qualification.

5. Major Inspection Related Project Activities

The welding was performed using a dry welding habitat (shown in Figure 2), which was located on top of the main pipe and allowed two divers to work without breathing apparatus in a hyperbaric environment. The first welding process was to lay down a buttering layer (shown in Figure 3) to cover the area where the stub was to be attached. This layer was tested manually using normal incidence compression wave, creep wave and shear wave techniques to inspect for possible lack of fusion, slag inclusions or cracking in buttering layer or parent pipe material. The 16-inch stub weld (shown in Figure 4) was subsequently welded on to the buttering layer and this was the subject of the most intense scrutiny.
Figure 2. Welding Habitat

Figure 3. Buttering Layer

Figure 4. Stub Weld
6. Design of the Inspection Procedure

Shear wave pulse echo techniques were selected; however due to the nature of the nozzle type geometry of the weld, this was not totally straightforward. In order to maximise coverage it was decided to test using 45, 60 and 70-degree transducers from both the 16 inch stub weld surface and the 36 inch pipe surface. Ray tracing using CAD methods was employed to determine probe locations and coverage around the varying geometry, as indicated in Figure 5.

![Figure 5. Example of Ray Tracing](image)

Modelling of the ultrasonic inspection was performed using the CIVA 3-D UT software; this was quite comprehensive and included a range of target defects (different shapes, tilt and skew, and roughness). In addition, the modelling compared the response of using hemi-spherical, round-bottom holes (RBH) with more conventional side drilled holes (SDH) and flat bottom holes (FBH); this allowed the use of RBH’s in the test pieces that simplified the design. The use of the modelling, in conjunction with ECA analysis, allowed evaluation of detectability of critical defects in critical regions of the weld zones.

7. Scanner Development

The scanner used was the Sonomatic Nautilus 2-axis motorised, diver deployed, system that was controlled by an engineer on the DSV through a 250-metre umbilical. However two significant scanner developments were required:

1. The addition of a “trombone” arm to allow scanning of the probes from the 36 inch pipe surface whilst the scanner was clamped to the 16-inch stub piece. This is shown in Figure 6.

2. The development of a motorised probe skewing facility to ensure that the probe beam was directed perpendicular to the weld plane. This is shown in Figure 7.
8. Test Pieces

Three test pieces were prepared to allow the AUT system to be mechanically and electrically proven, and to validate experimentally the ultrasonic performance compared with the modelling. Test Piece 1 was for scanning from the 16-inch stub and was used to assess overall sensitivity and the effects of tilt and skew. Test Piece 2 was for scanning from the 36-inch pipe and was used to assess overall sensitivity and the effects of tilt. Test Piece 3 was for scanning from the 36-inch pipe and was used to assess effects of skew. All reflectors used were artificial and were of controlled shape, orientation, size and location; RBH’s were used to assess sensitivity, FBH’s were used to assess the effect of tilt and notches were used to assess the effects of skew. There were many challenges associated with the specification, design and fabrication of the test pieces however the effort involved was considered to be very valuable.

9. Validation Work

A series of workshop-based trials were performed on the test pieces using manual ultrasonic testing and AUT. These were repeated a number of times with some variables but essentially using the same procedure. Due to the number of reflectors in the test pieces and the relatively high reporting sensitivity, a substantial amount of
data was produced. These were all analysed for content and repeatability, and then compared with the results from the CIVA modelling. The data all correlated favourably for detection and location of indications; there was a spread of typically 4dB in terms of sensitivity.

10. Data Presentation

For the AUT, all the data was collected digitally – position data and full UT waveform digitisation thus allowing the data to be presented in A-scan, B-scan and C-scan formats. This data could then be used with the CAD drawing to identify the location of indications and features. An example is shown in Figure 8.

![Figure 8. Example of Data Presentation](image)

11. Technical Justification

The Technical Justification involved assembling all evidence on the effectiveness of the test including previous experience of its application, laboratory studies, mathematical modelling, physical reasoning and any other relevant input. The output of the Technical Justification is a Written Statement of the evidence that supports the case that a test is capable of meeting its requirements. It comprises a mixture of experimental evidence and theoretical assessment as appropriate.

Outcome: –It was demonstrated that application of the code compliant inspection in combination with good workmanship criteria would be expected to reject flaws exceeding the dimensions of the ECA criteria with a comfortable margin at a high confidence level.
12. Execution of Work

Following the completion of the trials and the acceptance of the Technical Justification, the equipment and team were mobilised to the DSV and undertook the NDT work. This was performed safely and effectively and the integrity of the weld was accepted. The rest of the fabrication was completed and the pipeline link was brought on stream in October 2007.

13. Acknowledgements

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1 DNV-OS- F101 2000 Submarine Pipeline Systems
3 European Methodology for Qualification ENIQ Report No. 2 EUR 17299 EN Issue 2