COOP-CT-2005-018267

'RiserTest'

Development of a guided wave long range ultrasonic inspection system for the examination of offshore sub-sea risers, steel catenary risers (SCR) and flowlines

Horizontal Research Activities Involving SMEs

Co-operative Research

Publishable Final Activity Report

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1. EXECUTIVE SUMMARY

The aim of this project was to implement a large-scale monitoring solution for detection of time dependent degradation - corrosion and fatigue cracking - in sub-sea pipelines and risers using ultrasonic guided waves. Such waves have the capability to travel long distances in metals (many tens of metres) so that long lengths of pipe may be examined from a limited number of test locations. Furthermore, by generating a circular wave travelling in the pipe wall from an encircling transducer tool, 100% of the volume of the pipe wall may be examined. Consequently this approach is highly attractive for examination of inaccessible areas, as only a limited number of access points are needed and no prior estimation needs to be made of the most likely location of degradation, as the whole pipe is monitored.

The main tasks in the project were:-

- To specify the requirements for the test system,
- To develop sensors and the associated electronics to meet those requirements,
- To enhance the techniques and procedures for performing long range ultrasonic testing (LRUT) for improved performance,
- To demonstrate the capabilities in the laboratory,
- To demonstrate the feasibility of performing such tests sub-sea by means of underwater demonstration of a prototype system and tests under high pressure to simulate depths down to 2,000 metres.

The principal achievements were the demonstration that generation and reception of ultrasound were feasible down to 2,000 metres depth and that an operational system was capable of detecting defects in riser pipe sub-sea.

2. PROJECT EXECUTION

2.1. Project objectives

The scientific and technical objectives are:

- To develop the world's first technology able to monitor and inspect deepwater steel catenary risers (SCRs) in the ocean continuously and to demonstrate this on a 16" diameter pipe in a hyperbaric chamber pressurised to an equivalent of 2100m water depth.
- To develop new and novel long range ultrasonic testing (LRUT) technology for the detection of corrosion in sub-sea flow lines and of fatigue cracks (and corrosion) in sub-sea risers and SCRs.
- To develop ultrasound focusing techniques so that deep narrow cracks can be distinguished from wide shallow ones of the same cross sectional area.
- To develop transducers and sensors for operation through pipe coatings that can be permanently installed on deep water SCRs and oil and gas pipelines with the ability to transmit test data to the surface.

The economic objectives are:

- To prevent fracture of risers and flow lines, thus ensuring continued production and avoiding the huge costs of clean up after a major oil leak.
- Decrease oil spillage clean up costs by developing improved inspection technology that can detect defects before failure can occur.
- To improve the competitiveness of the partner SMEs, enabling them to offer a unique technology to offshore operators.

The social objectives are:

- To reduce the risk to workers (divers and rope access technicians) operating in the near 'splash zone' region on offshore oil and gas production platforms.
- Elimination of labour intensive and monotonous underwater inspection tasks near the splash zone.
- Reduction in operator stress and error caused by the need for great attention to detail and NDT process variability.
- Reduction in exposure of contract workers to danger (fatalities in contract workers are 5 times those in process staff workers).

The environmental objectives are:

- The elimination/reduction of hydrocarbon leaks and spillages from offshore oil production platforms and floating production facilities due to a breach of containment resulting from corrosion and/or fatigue cracking of the oil transportation risers, steel catenary risers and flow lines.

The EC policy objectives are:

- This project supports the priority given by the EU to preventing oil pollution from offshore pipelines and to the health and safety of workers. In addition to the Petroleum Act 1998, other legislation puts further controls on the discharge of hydrocarbon pollutants. Prevention and control is required by EU Directive 96/61/EC. Furthermore, the new proposed EU Liability Directive makes companies and individuals liable for damage they cause to the environment. This will put increasing onus on the offshore oil and gas industries to ensure the greatest possible safety for their activities.

2.2. Project Partners

The **Risertest** project is a collaboration between the following organisations:

2H Offshore Engineering Limited	UK
Atlantis NDE Ingeniería de Inspeccíon no Destructiva SL	Spain
BP Exploration Operating Company Limited	UK
Coaxial Power Systems Limited	UK
Dacon AS	Norway
Det Norske Vertias plc	Norway
I&T Nardoni Institute	Italy
Petroleo Brasileiro S.A.	Brazil
Przedsiebiorstwo Badawczo-Produkcyjne OPTEL SP. ZO.O.	Poland
TWI Limited	UK
Zenon S.A. Robotics and Informatics	Greece

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The Project is co-ordinated and managed by **TWI Ltd.** and is partly funded by the EC under the Co-operative SME programme, reference number **COOP-CT-2005-018267**.

2.3. Approach

The project was divided into a number of work packages:

		Lead Partner
WP A	Sample preparation and system specification	2H Offshore
WP B	Development of a sub-sea system	OPTEL
WP C	Development of LRUT focusing and beam steering	CPS
WP D	Development of LRUT procedures for SCRs, risers and flowlines	Atlantis
WP E	Production of a marinised LRUT system	2H Offshore
WP F	Laboratory and in-water trials	Dacon
WP G	Field trials	TWI
WP H	Project management	TWI

2.4. System Requirements

2.4.1. System Specification

The requirements for the system were evaluated for 3 different cases: Fixed risers, Flow lines and Steel Catenary Risers. The operational parameters for the system are given in Table 1, below.

Table 1 Summary of equipment specifications

	Risers	Flow-lines	Steel Catenary Risers
Underwater			
Permanently fixed			
ROV deployed			
ROV operated			
Above water			
Buried			
Pipe diameter	6”-18”	6”-24”	12”-36” (Thicker in deep water)
Pipe wall thickness	12.7-24mm		18-24mm
Defects	Internal and external corrosion, erosion, dents	Internal and external corrosion, erosion, dents, buckling, ratcheting.	Fatigue cracks at weld roots
Flanges	Treaded connectors	Yes at fir-trees and manifolds	No
Coatings	Splashtron	Coal tar, asphalt enamel surrounded by weighting concrete.	Thick proprietary insulation
Field joints	Coated in splash zone	Covered in sealant – possible corrosion sites	Covered with a ‘weld pack’ of insulation
Linings	Epoxy	Epoxy	Cladding
Geometry	Straight, elbows or pulled bend	Bends, double at expansion loops	Straight
Power supply	Surface	ROV	Remote, battery, wave, current, sacrificial anode.
Marinisation	Water proofed	Encapsulated	Oil-filled
Calibration welds	Yes	Yes	No
Data interpretation	Real-time	Real-time	After collection

2.4.2. Samples

One of the issues with deep water risers is that there is a wide variety of designs and coating types. However, a common factor is that the pipes are of heavy wall thickness which is required for both pressure containment and for the overall strength of the riser. For the final demonstrations of the system 12” (323mm) diameter pipe with 27mm wall and 3mm polypropylene coating was chosen to be representative of pipe used for deep water risers. One of the pipe sections used for the final demonstration of the system is shown in Figure 1.

Figure 1. 12" Diameter, 27mm wall polypropylene coated pipe used for the final demonstration

2.5. System Development

Transducers, deployment methods and the electronics to drive the system were investigated to design a system that would meet the operational requirements highlighted above. An important element was to determine whether:

- The ultrasonic transducers would be capable of operating down to the target depth of 2,000m (equivalent pressure 200 Bar).
- The high external pressure would affect the propagation of the ultrasound.

To establish this two marinised transducers were tested on a 1 cm² square section steel bar placed vertically in a water filled hyperbaric chamber. A longitudinal type (S_0 mode) wave was transmitted down the rod from one transducer to the other. Data were collected from 40 kHz to 120 kHz in 10 kHz steps in the dry and at pressures from 0 bar to 150 bar in 15 bar steps in water in order to investigate if the transducers function at up to 150 bar pressure and to determine what effect the water pressure had on the wave propagation

The results are shown in Figure 2 below. There is an initial drop in amplitude when the rod is placed in the water. After this the output remained relatively constant as the pressure was increased, with the amplitude tailing off more at lower frequencies and increasing slightly at higher frequencies. There was no significant change in amplitude for all frequencies after the apparatus had been left at full pressure for 1.25 hours.

The amplitude dropped as the pressure was reduced to ambient, particularly for the lower frequencies. It is likely that this effect was caused by water ingress into the transducers. This would change the resonant frequency of the transducers therefore changing the output amplitude at each frequency.

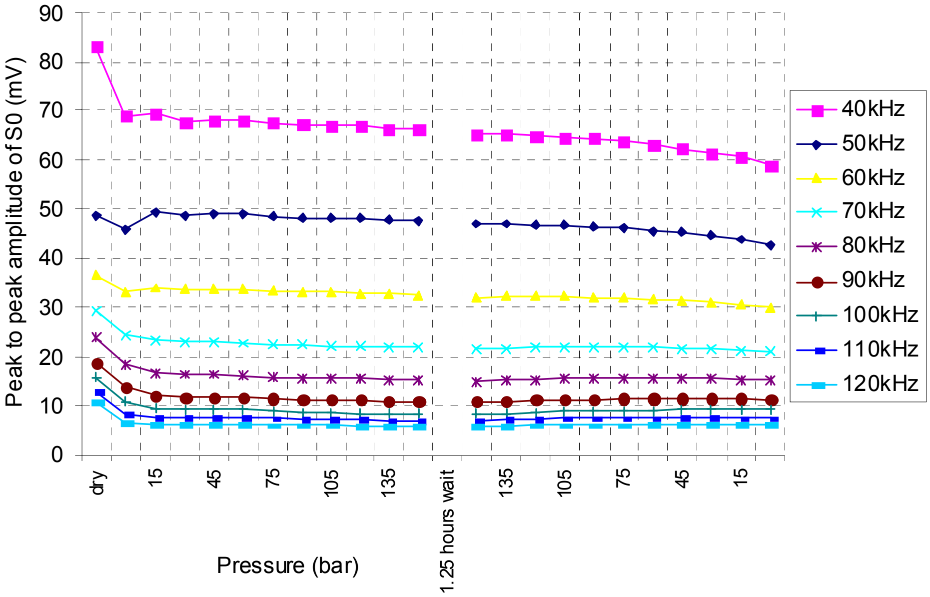

Figure 2. Effect of external pressure on transmitted ultrasonic amplitude

One of the marinised transducers was subjected to an additional test at a pressure of 200 bar for half an hour in water. This pressure corresponds to a water depth of 2000m. As this pressure was greater than the maximum permissible for the chamber at 2H Offshore, a smaller cylindrical chamber with a higher pressure rating was used. This, however, only allowed one transducer to be pressurised, and there was no room for a test bar. Consequently, the approach adopted was to check the performance of the transducer before and after the pressurisation cycle.

Before being pressurised the transducer was fully working and was tested on an aluminium strip. The peak to peak amplitude of the first received S_0 type pulse was 0.20 mV.

After being pressure tested, the transducer was retested on the same aluminium strip and the amplitude of the first received S_0 type pulse was 0.27mV, giving an increase in amplitude of 35%. The transducer was weighed before and after pressure testing. The mass was the same so no water had permanently entered the transducer.

It was concluded that:

- It is possible to transmit ultrasonic guided waves in steel at external pressures of up to 150 Bar (equivalent to a water depth of 1,500m). This pressure was limited by the capacity of the test apparatus.
- The prototype transducers worked satisfactorily at all pressures, although they did show signs of degradation towards the end of the test.
- In the limited additional test, the transducer worked satisfactorily after a pressure test at 200 Bar, equivalent to the 2,000 m water depth which is the target operational depth for this project.

2.6. Technique development

2.6.1. Assessment of defects

To gather sufficient information to improve the location and sizing performance of LRUT, it is necessary to combine the amplitude information yielded from symmetric tests with directionality information obtained from focused tests. A classification scheme has been designed to aid this process, whereby responses are given a score according to the amplitude from a symmetrical test, and their circumferential spread from a focused test.

First, each response is given a value from 1 to 3, known as it's Defect Category, C. This is calculated by taking the amplitude of the response relative to the expected amplitude of a weld signal (ie, the dB difference). Distance Amplitude Correction (DAC) curves are used to estimate the expected weld signal amplitude at arbitrary positions.
As such, C is defined as follows:

Received Amplitude from symmetric test is greater than 12dB less than a weld signal	C = 1
Received Amplitude is between 6dB and 12dB lower than a weld	C = 2
Received Amplitude is less than 6dB lower than a weld	C = 3

Figure 3 below, shows how these defect categories can be easily defined using distance amplitude calibration (DAC) curves.

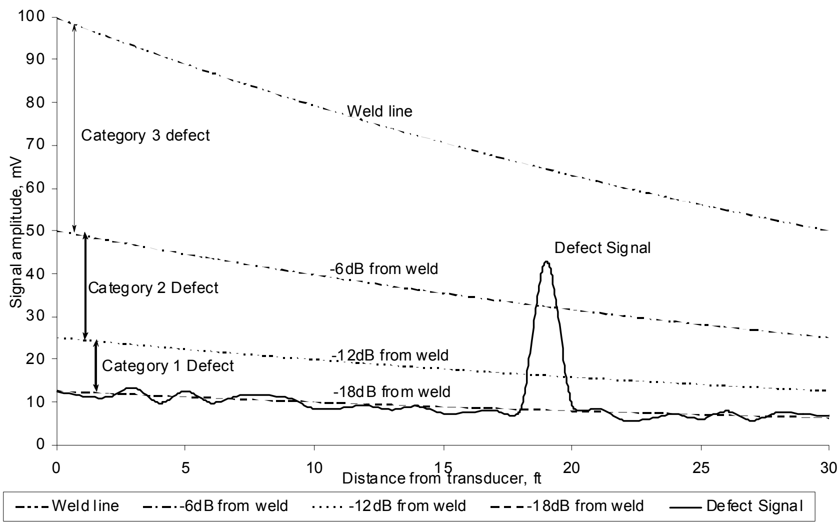

Figure 3. DAC lines indicating the Defect Category of a response. Should a signal from a reflector cross a DAC line, it will be interpreted as that level category defect

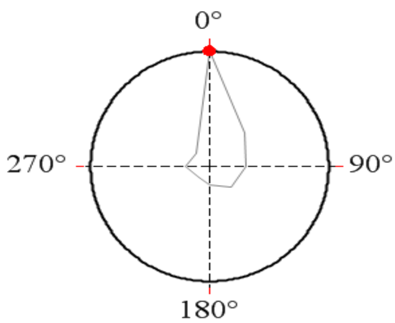

Figure 4. Radial plot of focused results showing how the distribution of reflected signals will vary according to the angular width of the defect

Secondly, a 'Directionality distribution' of the focused test, D, is computed. The directionality distribution is best described graphically, as shown in Figure 4, above, and is defined as follows:

Energy in response concentrated over less than 45° of the circumference	D = 3
Energy in response concentrated between 45° and 90° of the circumference	D = 2
Energy in response concentrated between 90° and 315° of the circumference	D = 1
Energy in response distributed evenly over 360°	D = 0

The product of C and D will then give operators a 'Follow-up priority'. Table 2 gives the follow-up priority matrix. If the C·D product is 3 or greater, high priority should be given. If C·D = 2, medium priority, and C·D = 1 low priority. If C·D =0, there is no directionality to the signal, so that it is interpreted as the reflection from a girth weld.

Table 2. Classification scheme of follow up priorities

Follow up priority	Defect Category, C			
Directionality Distribution, D	0	0	0	0
	1	1	2	3
	2	2	4	6
	3	3	6	9

This classification scheme has been tested on 'blind' trials of 406mm diameter coal tar coated cased pipe containing artificial defects, manufactured so as to mimic those typically experienced in field conditions with good success. During the R & D project phase, for the purpose of having performance targets, the technical team defined the threshold for 'Moderate', or 'Severe' defects. (For characteristics with dimensions less than that defined for 'moderate', those defects are characterized as 'small'.) The above methodology was employed and the Follow-up Priorities were calculated for each defect. Table 3 shows the relationship of actual defect size with the assigned Follow-up Priority classification given to the defects.

Table 3. Results of trials for the classification scheme. Grey cells indicate the 'correct' classification. Note that all 23 severe defects were allocated 'high priority', and all welds were correctly identified

Shaded cells show the ideal classification		Actual Defect Classification			
		Weld	Small	Moderate	Severe
Number in Sample		5	0	5	23
Interpretation of defects according to classification scheme	Weld	5			
	Low Priority			1	
	Medium Priority			1	
	High Priority			3	23

Note how all welds were correctly identified as welds, and all severe defects were allocated a high Follow-up Priority. Moderate defects were also detected, with conservative estimations of Follow-up Priority usually assigned to them. There were no 'Small' defects in the sample specimens.

2.6.2. Assessment of corrosion

A series of experiments was carried out on both bare and coated pipe to determine the performance of guided waves for the detection of metal loss defects, such as corrosion. Both regular defects of known size, in the form of drilled holes, and irregular defects made by grinding, were examined. Examples are given in Figures 5-7.

Figure 5. Defect in bare pipe consisting of drilled holes

Figure 6. Irregular defects in bare pipe, made by a series of grinding marks

Figure 7. Defect in coated pipe, width 80mm, length 92mm, reduced area 5.8%

The experiments carried out on the two last coated samples demonstrated the feasibility of the inspection for pipes with coatings. In the worst case maximum inspection length is of the order of 8m, but this length can increase to about 12 - 15m if we take account that for the pipe an effective alarm threshold for reduced area could be greater than 10%.

Table 4 summarizes defect echo amplitudes compared defect by defect with the relevant real reduced area.

Table 4. Results from tests to determine size of the defects

sample ID	defect n°	reduced area [%]	estimated reduced area [%]	Attenuation [as max inspection length in meter]
sample 1	D1	26	>30	>50
sample 2	D1	2.5	9	>50
"	D2	5	7	>50
"	D3	7.5	10	>50
"	D4	10	17	>50
sample 3	D1	16,32	9	>50
"	D2	7,76	3	>50
sample 4	D1	12	6	8
sample 5	D1	2,6	3	15
"	D2	5,8	4	15

We can observe that corrosion like defects on coated sample are generally a bit underestimated but, since the guided wave method is a screening technique, this is not really a problem. What is important is that all the defects are always well detectable and this means that the inspection can be reliable when carried out with the guided wave method.

2.6.3. Assessment of fatigue cracks

The aim was to determine the performance of LRUT for the detection of growing fatigue cracks. A permanently mounted sensor was used in conjunction with a fatigue test in a specially designed test rig. The samples to be fatigue tested were 6m long sections of risers, containing 1 – 3 girth welds. The fatigue test set-up is called "resonance fatigue testing" and involves bringing the pipe in a resonant bending motion. The purpose of this is to enable a highly accelerated test to be performed so that the time taken for cracks to appear is sufficiently short for the testing process to be efficient.

The objective of monitoring these resonance fatigue tests was to determine the performance of the current state of the art LRU technology in terms of crack initiation detection and crack growth monitoring accuracy.

A number of experiments were carried out, resulting in the use of a permanently mounted sensor to withstand the stresses of the resonance rig, Figure 8.

This development is particularly relevant to the installation of instrumentation of risers before installation, where LRUT sensors could be placed on the riser prior to submerging the pipe in the sea.

Figure 8. Permanently mounted sensor tool on the riser pipe in the resonance fatigue rig.

A further aspect of this work package was to demonstrate that the test system was not affected by long term exposure to marine conditions. This was achieved by subjecting a permanently bonded transducer to a long term salt spray test. To do this, a small-scale specimen was produced and the tool bonded to it. The pipe was a standard 8” (219mm) diameter steel tube, 1 metre in length, to fit the salt spray chamber. Figure 9 shows the pipe and the transducer tool in the salt spray chamber.

Figure 9. Specimen mounted in the salt spray chamber. The lead for conducting the in-situ ultrasonic tests may be clearly seen

The results showed that whilst there is some variation between the successive tests, the differences between the readings, including the initial baseline, are 0.4dB for the first peak, 3.3dB for the second and 2.2 dB for the third. There is some evidence that the system settles down after a period in service so that later readings differ from the baseline, but are very similar to each other.

It was concluded that the permanently mounted transducer system offers potential for the monitoring of pipelines and risers over long periods in a marine environment for the detection of time dependent degradation such as fatigue cracking.

2.7. Sub Sea System

2.7.1. Electronics

The concept is to mount the card cage containing the pulser-receivers and the control board in a frame which fits inside a pressure-resisting enclosure. The concept design is shown in Figure 10. This is basically a cylindrical design with domed ends. The ends are sealed by ‘O’ rings and contain penetrations for the umbilical and leads to the transducer tool.

The design depth for the enclosure is 300m.

Figure 10. Arrangement of the card cage inside the enclosure

The domed ends of the enclosure contain penetrations for the data umbilical and on/off switch at one end and for the tool lead at the other. The marinised tool lead is fed to a splitter box which divides it into 8 separate leads which are each connected to one of the 8 segments of the tool. The general arrangement is shown in Figure 11.

Figure 11. CAD representation of the marinised system showing the electronics enclosure and the tool lead

The complete electronics enclosure for the field trials is shown in Figure 12, below.

Figure 12. Assembled electronics package in the pressure housing

The ultrasonic transducer consisted of a bracelet tool. The transducers, the transducer holders and the interconnecting leads were all sealed with either 'O' ring seals or by use of proprietary marinised connectors. The bracelet tool is shown in Figure 13.

Figure 13. Detail of the sub-sea bracelet tool, showing the underwater connectors

The completed system is shown in Figure 14, below.

Figure 14. Completed sub-sea test system ready for the field trials

2.8. Field Trials

To demonstrate the applicability of the prototype system to the inspection of sub sea risers and flow lines, the project team decided that the system would be tested by performing an underwater test on a representative pipe. The target was to demonstrate the satisfactory performance of the prototype at 10m depth. The test facility was made available by DNV at their premises in Bergen, Norway. This had waterfront access which allowed the pipe specimen to be lifted by crane and lowered into the sea.

The objectives of the field trials were:

1. To establish correct system operation on a bare reference pipe specimen.
2. To determine the sensitivity to defects in the reference pipe.
3. To establish the influence of the coating on the representative riser pipe specimen on the test signals.
4. To establish the effect of the coating on the sensitivity to defects in the riser pipe specimen.
5. To demonstrate satisfactory operation underwater, see Figure 15.
6. To investigate the effects of depth on the system performance.
7. To determine the influence of immersion on the sensitivity to defects.

Figure 15. Prototype sub-sea system mounted on the coated riser pipe

The pipe, with the tool mounted on it was lowered into the sea on a crane, Figure 16.

Figure 16. The test pipe being lowered into the sea

During the sub-sea tests the pipe was monitored by a small ROV with at video camera, supplied and operated by Dacon. Figure 17 shows a video picture of the tool operating underwater.

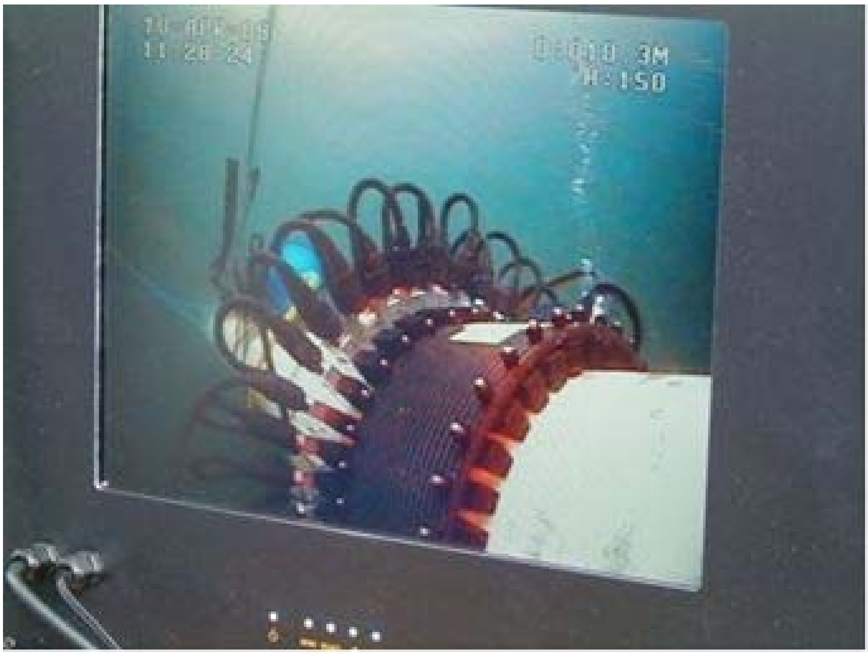

Figure 17. Underwater video picture of the Risertest tool in operation

The system was checked initially with the pipe just submerged (0.5m below the surface). The result is shown in Figure 18.

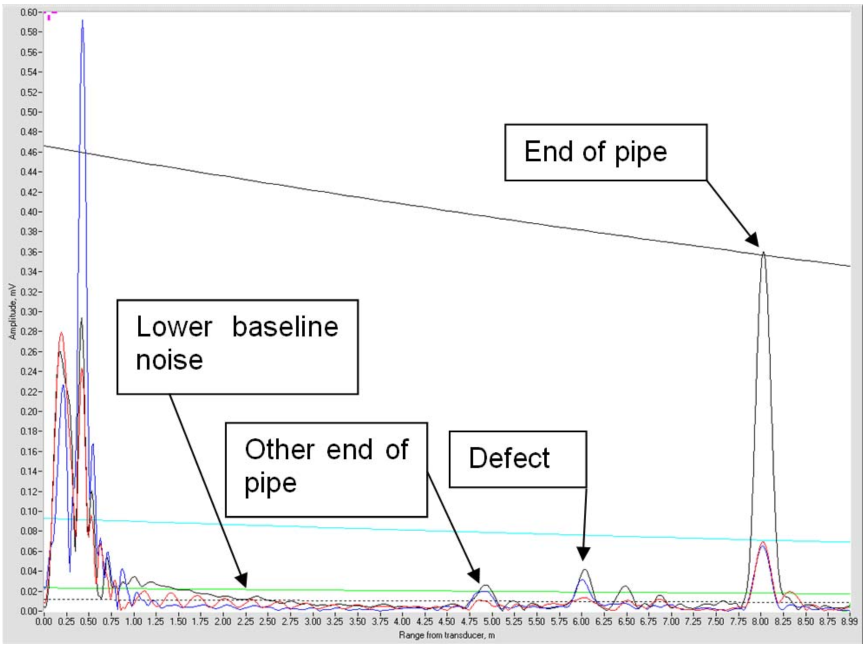

Figure 18. Result from the just submerged test (0.5m deep) on the coated pipe

The results were virtually identical to the in-air tests. Placing the pipe in water does not affect the result. If anything, some of the reverberation at the start of the trace is reduced, improving the overall signal to noise ratio.

The pipe was then lowered deeper into the water in 5m increments. The results were largely unaffected by the water depth. The deepest test was at 14.5m, 4.5m deeper than the original target depth of the trial. For each depth, the echo from the end of the pipe was used as a reference and the signal amplitude from the defect was compared with it. The signal to noise ratio was monitored at each depth. The results are shown in Table 5, below.

Table 5. Difference in amplitude between end of pipe response and the defect response

Depth (m)	Difference in amplitude (dB)
Dry	17.5
0.5	18.9
5	19.8
10	21.7
14.5	19.3

It may be seen from the table that there is little difference in the defect to pipe end ratio as the depth is increased. In fact, the maximum difference is 4.2 dB.

2.9. Conclusions

In conclusion, the in-air and in-water tests showed that:

- The prototype system performed without fault at all water depths, down to 14.5m.
- There were no significant differences between the results for defect detection and positioning for the in-air and in-water tests.
- The depth had no influence on the test results.
- The pipe coating present had no significant effect on the test results.

3. DISSEMINATION AND USE

As project coordinator, TWI hosts a web site for the Risertest consortium at www.risertest.eu.com (Figure 19). It is intended that the prototype system used developed under the project is used as a basis for soliciting commercial applications for long range ultrasonics underwater.

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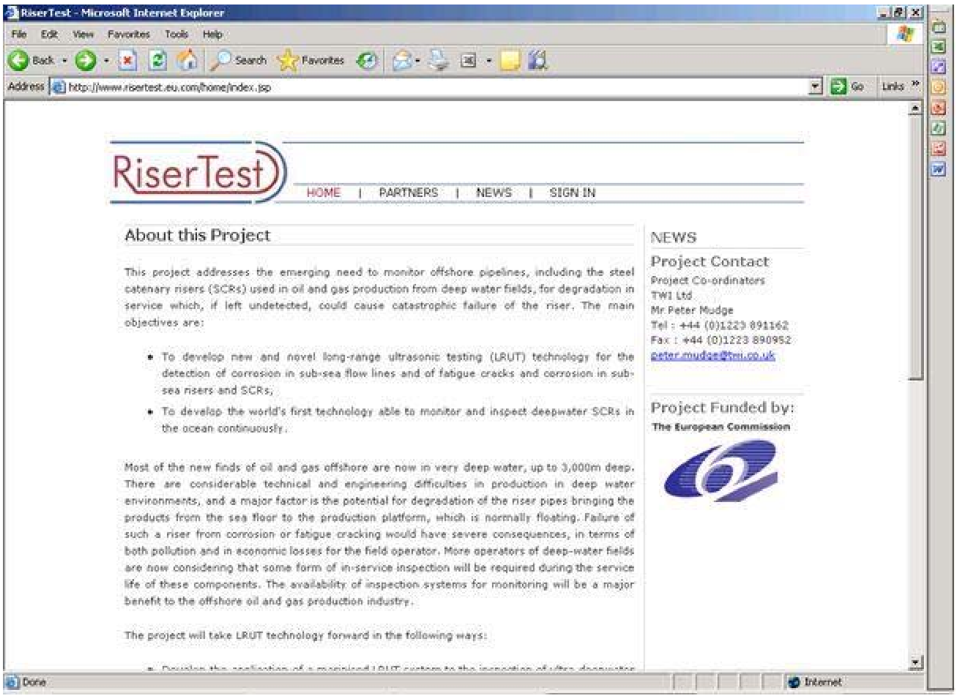

Figure 19. Risertest Website