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Digital Radiography Inspection of Flexible Risers in Offshore Oil and Gas Industry

E. Cheilakou[1], N. Tsopelas[1], T. Brashaw[2], A. Anastasopoulos[1], P.I. Nicholson[3], A. L. Clarke[3], T. Sattar[4], A. Kaur[4], B. Ma[4], K. Shah[5], M. Kimball[5], G.S. Virk[5], M. Corsar[5]

[1]MISTRAS Group Hellas A.B.E.E., 7 EL. Venizelou, 14452 Metamorphosi, Athens, Greece
[2]MISTRAS Group Limited, Norman Way Industrial Estate – Over – Cambridge CB24 5QE
[3]TWI Technology Centre (Wales), Harbourside Business Park, Port Talbot, SA13 1SB, UK
[4]London South Bank University, 103 Borough Road, London SE1 0AA
[5] Innovative Technology and Science Ltd, Hildersham Road, Cambridge CB21 6DR, UK

Abstract

This paper presents the development of a digital radiography-based system for sub-sea applications that is being implemented within the context of a H2020 EU funded project called "RiserSure". The system is capable of performing semi-automatic in-situ integrity inspections and providing detailed information on any damage to the metallic layers of flexible risers, without the need to remove the coating layer. The integrated system comprises a subsea digital radiography linear detector array coupled to a commercially available marinised gamma ray source, and a bespoke developed versatile scanning system for deploying the radiography units under subsea conditions for performing precise all-round scanning of risers. Preliminary site shallow sea trials of the prototype system were conducted at the Underwater Centre facilities in Fort William, Scotland. The results, discussed in this paper, validated the effective underwater application and performance capabilities of the system in controlled shallow sea operating conditions, and show the potential for offering reliable and highly accurate radiographic inspection of risers. Finally, from the site trials, the requirements for further system improvements were identified for real-world deployment.

1. Introduction

Flexible risers are critical infrastructure in floating production operations in the Oil & Gas industry and are typically exposed to harsh environmental conditions. These risers are multi-layered structures comprising different materials and serving different functions including withstanding internal and external pressure, preventing leaks of hydrocarbons, coping with tensile forces and protecting against seawater. Current conventional NDT techniques, such as Visual, Ultrasound or Eddy Current inspection, suffer from several drawbacks that prevent reliable assessment of flexible risers' subsea condition and thus cannot provide advance warning of failure. More specifically, visual inspections are slow and expensive and can only detect gross damage after it has occurred. Eddy current techniques only provide information on the very outmost region of the steel components, while Ultrasound cannot penetrate the air filled annulus or other discontinuities in the structure.

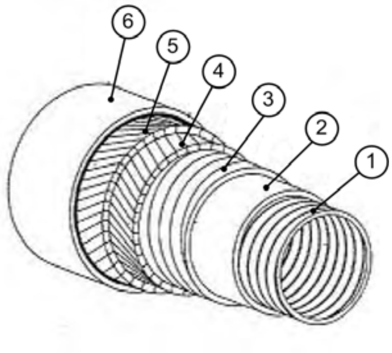
Radiography is an ideal technique for flexible riser inspection as it can penetrate through all the layers in the pipe providing a fuller picture of the entire riser structure. Traditionally, radiography film and phosphor plates are used as the detection media in underwater radiography. However, this type of radiographic detection media is more suited for on-shore and not sub-sea application, as there is a requirement to return the detection media to the surface every time a radiographic image is acquired for developing and processing. Digital Radiography is now common in the NDT industry and a digital detector array allows the possibility for the acquired images to be conveyed via an umbilical to the surface and in near real-time.

The present work is being implemented within the context of a H2020 EU funded project called "RiserSure", that aims to overcome the above limitations by delivering a novel digital radiography based system for sub-sea applications that will provide rapid, real-time, and high-resolution scanning of the complex riser structure without the need to remove the coating layer. RiserSure is designed specifically for flexible riser inspection offering significant advantages compared to existing solutions. This includes simple and cost-effective deployment for both sub-sea and within the splash zone, with operating capability at up to 100m depth range covering the highest risk areas of the riser structure. The RiserSure system is designed for advanced warning of metal wire deterioration before failure. Since there is not a requirement for removal of the riser from service (Kaur, 2018) this will allow for planned maintenance, as well as zero downtime or loss of operating revenue. Additionally, it will benefit society by reducing the risk of accidents and environmental damage from offshore oil and gas production.

This paper presents the current stage of development of the integrated RiserSure system, comprising a subsea digital radiography linear detector array coupled to a commercially available marinised gamma ray source, and a bespoke developed versatile scanning system for deploying the radiography units under subsea conditions for performing precise all-round scanning of risers. Preliminary site trials of the prototype system aiming to evaluate its underwater application were conducted at the Underwater Centre facilities in Fort William, Scotland, and are demonstrated in this paper as well. Finally, the performance capabilities of the system in controlled shallow sub-sea operating conditions and the requirements for further system improvements for real-world deployment are discussed.

2. Flexible Riser Construction

The trials detailed in this paper focussed on the inspection of a common rough bore, high pressure flexible riser and therefore the initial RiserSure technology was designed for this purpose. These risers are constructed in layers, as detailed in Figure 1. The specific sample used in these trials measured 6m long, with a nominal 220mm outer diameter and was supplied by GE Wellstream.



Layer	Description	Material	Thickness (mm)
1	Interlocked carcass	304L (Fe02)	8.5
2	Internal pressure sheath	Rislan	12.5
3	Pressure armour (zeta layer)	Steel SAE 1045	8
4	Internal pressure sheath	Rislan	6.5
5	Inner tensile armour layer	Steel SAE 1060	4.25
	Outer tensile armour layer	Steel SAE 1060	4.25
6	Polyethylene external sheath	PA-11	6.5

Figure 1: Layer structure of a common rough bore, high-pressure flexible riser.

3. Integrated RiserSure Technology

The integration phase of the project represented a significant step change in the RiserSure system technology readiness as it was the first time the RiserSure sub-components had been combined into one system. Prior to the integration stage, the radiographic detector and source holder had only been tested, in isolation, in laboratory conditions. The detector had only ever been tested with a general purpose laboratory manipulator, rotating a test riser rather than rotating the detector. An additional factor was that X-ray radiography rather than Gamma radiography had only been used in the testing as the system had not been deployed underwater. Fortunately, the hardware and software of the robotic system are based on a modular structure that facilitates easy integration of additional hardware units in the system and respective software components.

The system configuration of the RiserSure inspection system, comprising robotic hardware and the radiographic modules, is shown in Figure 2.

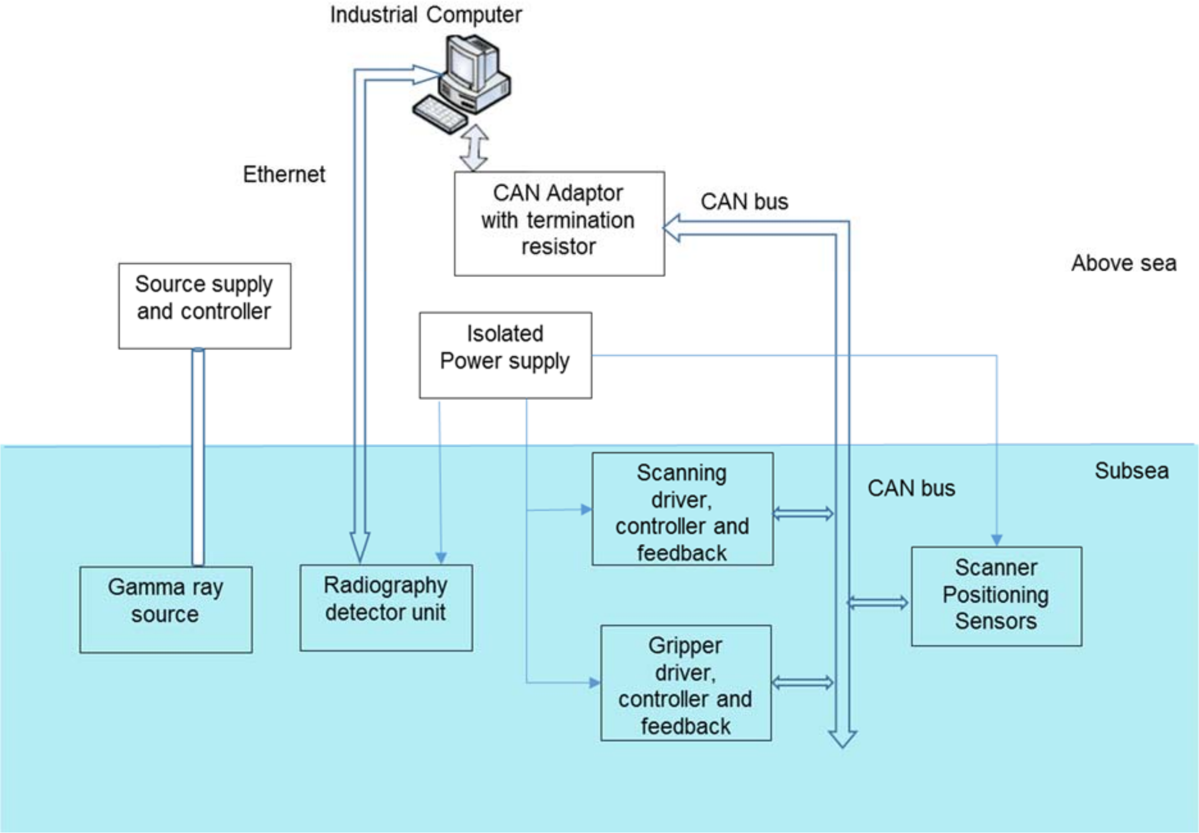


Figure 2: RiserSure inspection system configuration.

4. Scanning System

The robotic system for RiserSure has been designed to deploy and carry out the riser's inspection in a subsea environment. The system has the capability to carry the radiography unit to the point of inspection, securely hold its position and complete a 360^{o} scan of the riser, as well as to scan at varying speeds to adapt to the required exposure time for radiography inspection. As the majority of risers are of 250mm diameter or less in the North Sea, the robotic system has been designed to cater for flexible risers of up to 250mm, however, its design can easily be scaled up to accommodate larger diameters. The scanning speed is precisely controllable to 0.01 rpm for the given payload to provide sufficient exposure time for the radiography to image the risers' internal metallic layers and detect small defects.

The prototype robotic system's structure is based on an open platform that facilitates easy positioning around the riser with minimal manual intervention. The main structure comprises C-shaped mounting plates coupled by threaded rods and a two-piece precision rotary ring gear that is used to carry and rotate the radiography units. The only part of the scanner that requires intervention to open to encircle a riser, close and lock into position is the one segment of the precision rotary ring gear and can easily be adapted to be deployed using ROVs if required. The rotary ring gear is actuated by a motor-driven pinion gear, and floats on thrust bearings fixed permanently on a base plate. A 3D CAD model of the prototype is shown in Figure 3.

It is important that there is very little movement or vibration in the RiserSure system during scanning to minimising any blurring in the resultant radiographic image. Therefore, in order to keep the radiography units stable against the wave disturbances during inspection, and to avoid any collisions with the riser surface, a gripper system consisting of linear slides has been incorporated that holds the riser at two positions during scanning. The gripper system design parameters are derived from the wave disturbances data and on the assumption that it will be a clean riser surface ensuring the coefficient of friction between the gripper and riser surface used at the design time. The robotic system is moved along the riser using a winching system installed on the topside platform.

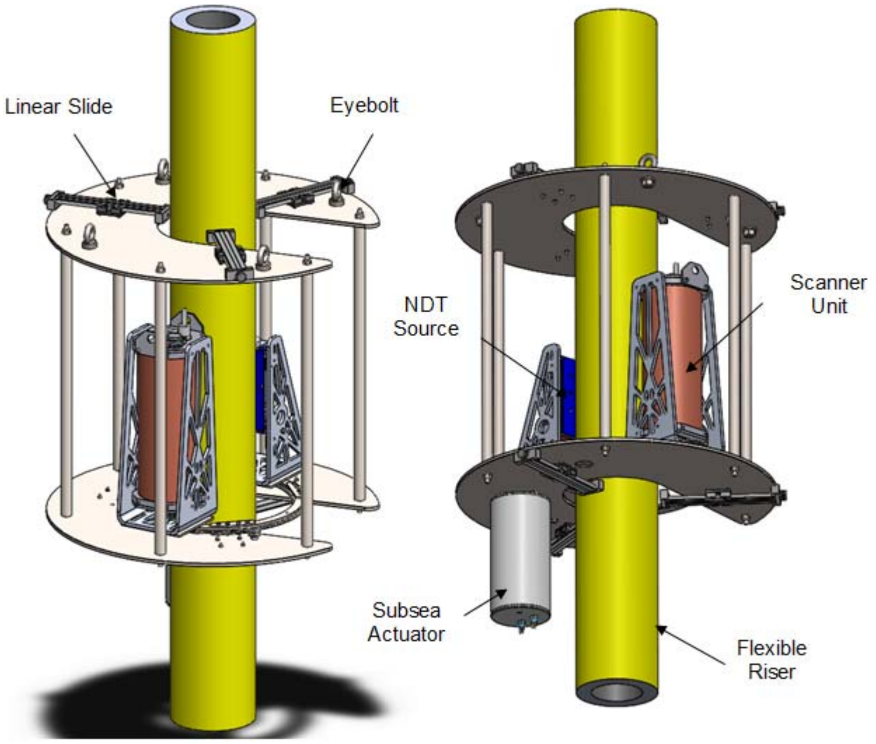


Figure 3: 3D CAD model of the prototype robotic inspection system.

The gripping and scanning system of the riser are implemented using customised subsea actuators. Each of the actuators consists of motor, the drive electronics and control circuitry integrated within the stainless steel oil-filled subsea enclosures. Each actuator also includes position feedback, current limit control, internal temperature and status monitoring registers.

The low level controls for each actuator are implemented in the integrated controller, and the supervisory control of the whole system is implemented in the dedicated industrial computer which is operated remotely at the topside. All the robotic subsea units are connected to the topside unit using the serial communication bus interface. Each actuator is identified with its own unique id for protocols implementation. The actuators are connected to each other using daisy chain configuration and to the topside unit via a single integrated umbilical that consists of the power cores and the twisted pairs for communication link.

The supervisory control on the topside is a GUI (graphical user interface) based system. This includes the control of system operational modes based on user inputs and internal system parameters, monitoring of critical parameters of subsea units, display of system status and warnings of system errors. Further consideration is given during implementation to timing parameters for sampling of inputs, display updating rate, continuous position monitoring of the robotic system, display of modes being executed, checks on user inputs and provision for stopping execution for any of the operational modes.

The winch system is a subsea certified commercially available system which is operated independently. The position of the scanner along the riser is encoded using the encoder on the winch and the subsea depth sensor. However, for safety purposes, before the execution of any operational modes, except the emergency stop, the user is required to confirm the operation, allowing the verification of external and internal systems' conditions. To resist the subsea environment and to withstand the environmental loading, all the mechanical parts and enclosures are manufactured from stainless steel (316L).

5. Radiography System

5.1. Radiographic setup

The RiserSure project has focussed on the use of Ir192 as the Gamma ray source because of its availability, and it can be used to examine thicker sections of metals compared to Se75. Indeed, this is the Gamma ray isotope of choice currently used by industry for conventional underwater radiography, and this helps with the RiserSure system's readiness to market. The use of Co60 is possible, but it is more difficult to handle due to its long half-life of 5.27 years and the associated strict HSE regulations and restrictions. As such the resulting cost of using Co60 is a lot of higher, and the storage of this source is more difficult for site trials.

By the nature of no access to the inside of the flexible riser, the radiography technique used is double wall double image (DWDI), and the setup is shown in Figure 3. This technique produces a radiographic image that contains data superimposed from the diametrically opposite walls of the riser in the same frame. The Gamma source is positioned as close as practically possible to the near side wall of the flexible riser, resulting in a blurred magnified image of the nearside wall overlaid with a clear image of the outside wall which is closest to the detector. The blurring of the nearside wall image is due to the geometric unsharpness caused by its proximity to the Gamma source. This does not affect the image of the outside wall, which remains clear, as it is further away from the Gamma source.

In determining the level of radioactivity required the materials that the Gamma radiation has to penetrate must be known. The key materials of a flexible riser are steel and polymer. Steel has a far higher attenuation coefficient than polymer, therefore only the steel will be considered in the model of the riser. The amount of steel within the 6m sample flexible riser is calculated as 25mm (see Figure 1). This is a nominal value because, in the same sample, a variation of +5mm in riser wall thickness was noted. Since double wall imaging radiography technique is being carried out, it can be approximated that the total steel thickness is nominally 50mm in air. Figure 4 shows the total radiation path length for an empty riser inspected in air.

In reality, a riser comprises multiple layers alternating between polymer and steel, as described in Figure 1. However, for the purpose of estimating total steel thickness the riser is drawn with just two layers, with each layer combining either steel or polymer. Likewise, for the purpose of total steel thickness estimation, the air gaps inside the riser, and the air gap between the riser and source and detector, can be considered negligible.

A calculated total steel thickness value of 50mm falls well within the limits of a steel thickness for inspection with Ir192. However, when the inspection is made in water there is additional material in the radiation path that needs to be penetrated since the detector and source are positioned a set distance from the riser surface. In addition, the radiation path is further attenuated when there is a liquid inside the riser. Water is more attenuating to radiation than oil and air. If we assume the worst case scenario, where the riser is flooded with water, it is possible to estimate the total equivalent steel thickness.

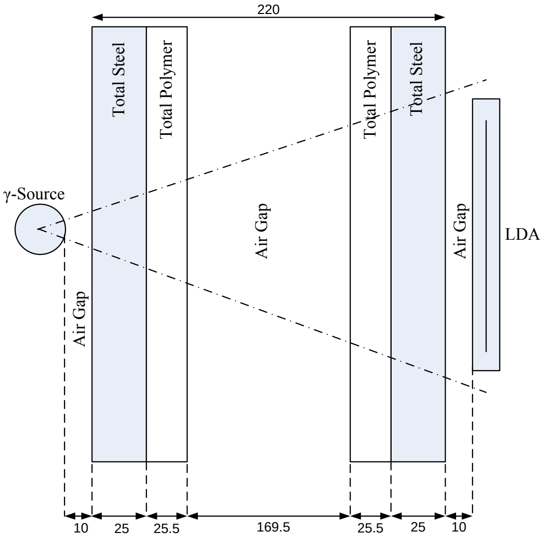


Figure 4: Total radiation path length for empty riser inspected in air (dimensions in mm).

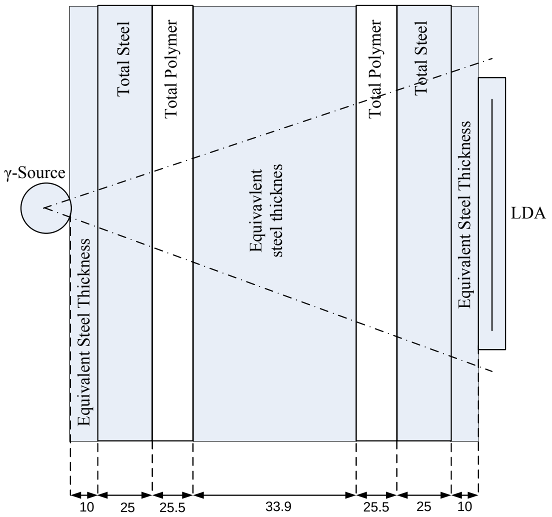


Figure 5: Total radiation path length for riser in water (dimensions in mm).

In terms of radiation absorption, it can be calculated that 1 metre of water is equivalent to approximately 20cm thick steel (Nicholson, 2010). Therefore, the total equivalent steel thickness the radiation has to penetrate, in order to enter and exit the riser wall, can be estimated. Figure 5 shows the total radiation path length for the riser sample in water. The riser is open-ended and therefore water is present both outside and inside the riser. In water, taking into account the source to object, and the detector to object distance, and the water distance in the riser, the total equivalent steel thickness is 103.9mm. This value falls outside the recommend maximum steel thickness that can be penetrated with Ir192 according to (GE Inspection Technologies, 2007; Gros, 1992). However, British radiography standards do state the penetrated steel thickness range for Ir192 can be up to 100mm (BSI, 2013) so for the sample used in these trials, it is just over the radiation penetration limit for steel.

It can be concluded that the radiation beam is strongly attenuated by water, and for the worst case scenario, ie riser filled with water and inspected in water, the very best results will not be obtained.

Using an alternative Gamma ray source such as Cobalt 60 (Co60) is a possible alternative in terms of radiation penetration. However, Co60 is not as widely used in industrial radiography. This is because the half-life is 5.27 years. Comparing this with Ir192 which has a half-life of 74 days, Ir192 is the more practical radiation source to use, but only for risers that do not exceed the total equivalent steel thickness penetration limits of 100mm.

Generally, flexible risers will be filled with oil rather than water. As oil has a slightly lower attenuation compared to water, there is scope for larger diameter or thicker walled risers to be inspected but this has not been investigated in the current work.

5.2. Imaging

The detector used is of the linear array type and has a 250mm active length comprising pixels at a 0.4mm pixel pitch. The detector is housed in a 316 stainless steel cylinder. A 21-pin subsea water-proof connector is incorporated in one cap end of the detector vessel to facilitate connection to the host PC.

A key factor in obtaining a high quality radiographic image with the RiserSure system is the synchronisation between the detector's image acquisition speed and the rotational speed of the scanner module. For optimal operation, the linear detector array (LDA) should acquire a line of the image each time the object moves a distance equal to the LDA's pixel width (assuming no geometric magnification of the radiographic image). If the detector acquires the line images too fast then the resultant radiograph becomes stretched, a too slow acquisition results in a compressed image, which could lead to image blur and small defects being masked and undetectable.

The RiserSure detector rotates around the riser to acquire images, meaning that the linear speed at which the varying materials of the riser passes the scanner varies with the depth into the riser that material is located. Therefore the detector should be set to acquire line images at a rate optimised to the depth of the layer of interest, or the mid-point between the two extreme layers of interest. The following equation is used In order to calculate the rotational velocity, *v*, at which the layer of interest passes the detector:

$$v = \frac{\pi f_m r}{30} \tag{1}$$

Or in the case of a mid-point between the two extreme layers of interest:

$$v = \frac{\pi f_m (r_o + r_i)}{60} \tag{2}$$

Where f_m is the rotational speed (or frequency) in revolutions per minute, r is the radial distance of the single layer of interest and r_o and r_i are the radial distances of the extreme outer and inner layers of interest respectively.

Therefore, for synchronous operation, the digital detector would have to operate with an exposure time, *t*, of:

$$t = \frac{30p}{\pi f_m r} \tag{3}$$

Where *p* is the pixel size of the LDA.

Yet this formula does not take into account the effects of any geometric magnification, whereby an increase in the distance between the layer of interest and the detector results in an increase in the size of the projected radiographic image on the LDA. To keep synchronisation the detector's exposure time would have to decrease proportionally. Even though in the case of RiserSure, the geometric magnification would be small, taking into account this factor would increase the accuracy of the estimation of the optimal exposure time, *t*:

$$t = \frac{30p}{\pi f_m r m} = \frac{30p(SDD - DOD)}{\pi f_m r \cdot SDD} \tag{4}$$

Where *m* is the geometric magnification, *SDD* is the source-to-detector distance and *DOD* is the detector-to-object distance.

In reality, the scanner speed of rotation has to react to detector exposure time, which is set by the user. The first reason for this is that the exposure time needs to be set correctly to ensure optimal gamma penetration to provide a good quality radiograph. Secondly, the detector exposure time can only be adjusted on an incremental basis, the scanner's speed of rotation can be set more flexibly. Therefore the scanner's speed of rotation is calculated by:

$$f_m = \frac{30p(SDD-DOD)}{\pi rt \cdot SDD} \tag{5}$$

5.3. Gamma ray source holder

An industry standard Gamma ray source holder (MKVI Nautilus) containing a Ir192 20.8 Ci pill with spot size of 1.5mm x 1.5mm was integrated into the RiserSure system for the trials. This source was hired from a third party provider Subsea SX and they accompanied the source holder and had the necessary licensing to facilitate transportation and storage. The source holder can be operated with either a pneumatic or hydraulic supply for controlling the exposure of the pill. Since the water depth in the trials was less than 7m, and the corresponding external pressure was not great, pneumatic control was used to reduce trial setup time. Subsea SX brought with them their own air cylinder for controlling the source holder via two 50m air hoses. Protection from accidental exposure is provided because the isotope pill is, by default, stored in the shielded part of the holder. The source is moved from the stored position to the exposed position by the actuator which is active by air. The actuation automatically returns to the source position in the event of an airline failure.

6. Site trials at the Underwater Centre (UC) in Fort William

6.1. Scope of work

Preliminary site trials of the prototype inspection system were conducted at the Underwater Centre (UC) facilities in Fort William (Figure 6), Scotland, in order to evaluate its underwater operation and performance capabilities in controlled shallow sub-sea operating conditions.

Figure 6: The Underwater Centre facilities at Fort William, Scotland (left image). The Underwater Centre Pier (right image).

For the system trials, the section of flexible riser, 6m long with a nominal 220mm outer diameter (supplied by GE Wellstream as mentioned above), was provided by TWI that is demonstrated in Figure 7a. A mobile crane was also used to lift and lower the assembly into the water off the edge of the UC pier, as shown in Figure 7b.

Various components of the RiserSure system including the bottom and upper platforms of the scanner, the mounting brackets accommodating the radiographic detector and source units and the mesh grating platform are shown in Figure 8. In addition, a video surveillance system, the "Spectrum 45" camera system by INUCKTUN, was utilised (Figure 9), in order to closely monitor the deployment tool while being lowered into position and whilst submerged for the early identification of any issues as well as to identify the points of interest for the positioning of the tool.

Figure 7: (a) Section of flexible test, 6m long and 220mm diameter, provided by TWI for the system trial. **(b)** Use of mobile crane to lift and lower the assembly under water.

Figure 8: Various components of RiserSure system prior assembling.

Figure 9: Spectrum 45 camera system.

6.2. Integrated system set up – Assembled scanner with riser

Once the scanning system was assembled, it was found out that the threaded rods utilised to join the bottom and upper platforms of the tool did not offer sufficient structural strength resulting in an unacceptable degree of flex in the structure of the tool. In order to overcome the above limitation, on-site modifications were performed by adding high strength tubing over the threaded rods between the plates, aiming to further strengthen the design and increase the structural capacity of the system, as shown in Figure 10. The above resulted in a far stronger structure by as much as 50% that will be taken into account in the final system design.

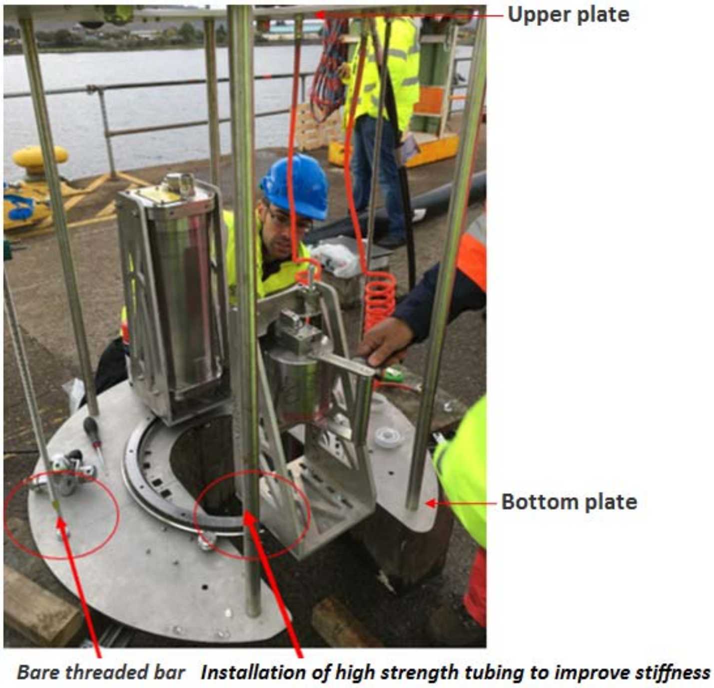


Figure 10: Scanner system being assembled for trials. On-site modifications for structural strengthening of the deployment tool.

The next step was to prepare the integrated set-up by inserting the sample trial riser into the assembled scanner from the top as well as from the opening side of the scanner and closing the ring segment (Figure 11a). The scanner system was then able to adjust to the riser curvature by manual adjustments of the linear slides on the top and the bottom platforms. For the implementation of the subsequent testing, the riser with the assembled tool was placed onto a mesh platform grating presented in Figure 11b, in order to support and protect the assembly and riser whilst placed on the seabed. Furthermore, the video surveillance camera was attached temporarily, and all cables and tethers were managed properly by routing and taping in a manner that avoided entanglement for the short drop to the seabed at the pier.

Figure 11: (a) Riser being inserted into the scanner from the top. **(b)** Placement of riser and assembled scanner onto mesh grating platform for seabed testing.

6.3. Subsea testing

Once all the key component parts were assembled around the riser, initial dry testing of the system was carried out to ensure that all key elements of the tool were operating correctly. This initial dry run proved to be a good functional testing of the overall system, as the gear drive for the rotating had come loose and required re-assembly to ensure subsea trials would go smoothly with no components coming undone during the wet testing. Once this had been re-secured and the dry test of the source and radiographic detector was completed, the entire assembly was lowered into the water (Figure 12).

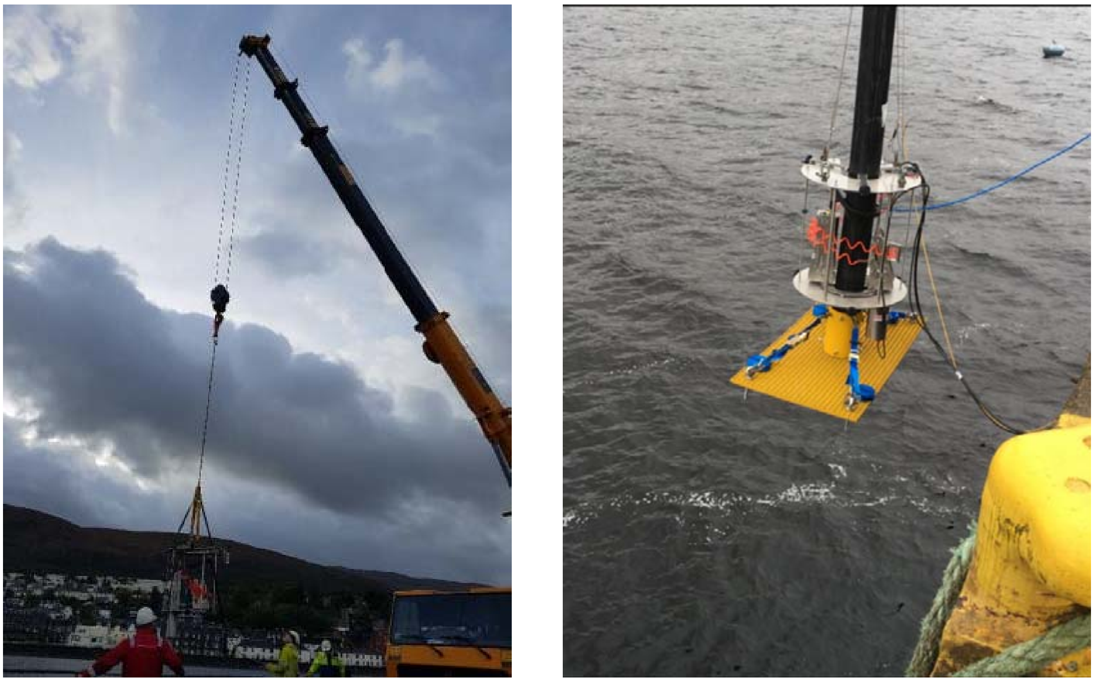
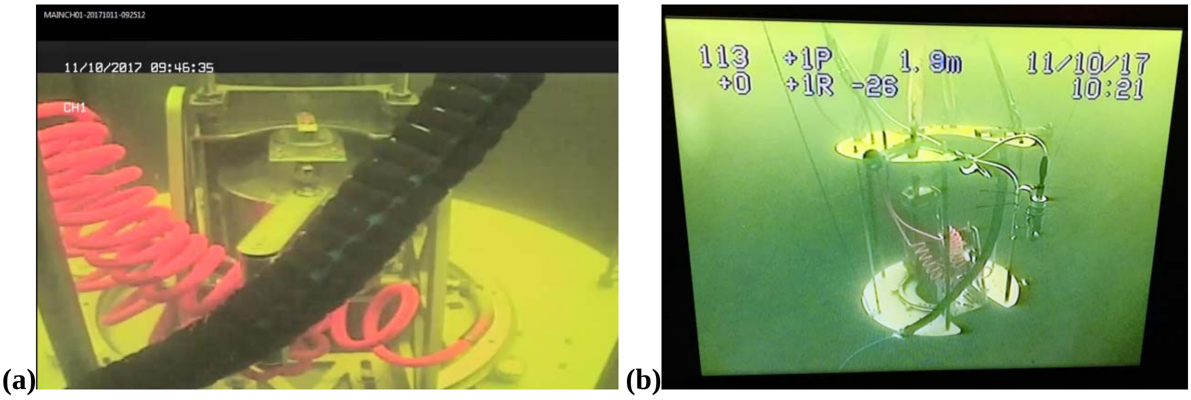


Figure 12: Assembly being lowered down to sea from pier for underwater testing.

The system was submerged to a shallow depth of 8 meters and radiographic testing was carried out in actual subsea conditions. The scanner operation was controlled by means of a remotely operated graphical user interface, installed on a personal computer inside a protected control room. During the test, the entire assembly was monitored using the video surveillance camera system Figure 13a, and the scanner was monitored rotating around the riser. An image of the submerged system captured by ROV is indicated in Figure 13b.



(a) **(b)**

Figure 13: Submerged system images captured by **(a)** the Spectrum 45 camera and **(b)** the ROV.

While submerged, a full circumferential scan of the riser was completed, and the resulting radiographic images were obtained. Radiographic images were taken at different exposure levels by varying the scanning speed from 0.03 to 0.06rpm. Once the full scan was completed the entire assembly was brought back onto the pier surface and all components were inspected for any post-test issues. No issues were identified, and the initial wet test was completed without any major issues to report.

6.4. Results and Discussion

The results obtained validated the effective underwater application and performance capabilities of the system in controlled shallow sea operating conditions, and showed the potential for offering reliable radiographic inspection of risers.

Highly accurate radiographic images were obtained clearly identifying the artificially embedded defect and indicating the internal metal wires mesh structure in high resolution. Representative radiographic images are shown in Figures 14 and 15. The radiographic image shown in Figure 15 with the horizontal axis representing a 360° scan and the vertical axis corresponding to the LDA length (250mm) was acquired in just under 15 minutes.

The use of the Linear Array Detector allows the tool to remain submerged for an unlimited amount of time, thus offering more than a screening tool. The ability to carry out a more detailed examination of smaller or larger sections is possible during the same trial, as well. The capability of the system to scan 360° of each section is a major benefit since it results in significant reduction of the time required to carry out the survey, while delivering images of superior quality compared to that provided by computed radiography and flat panel digital radiographic systems.

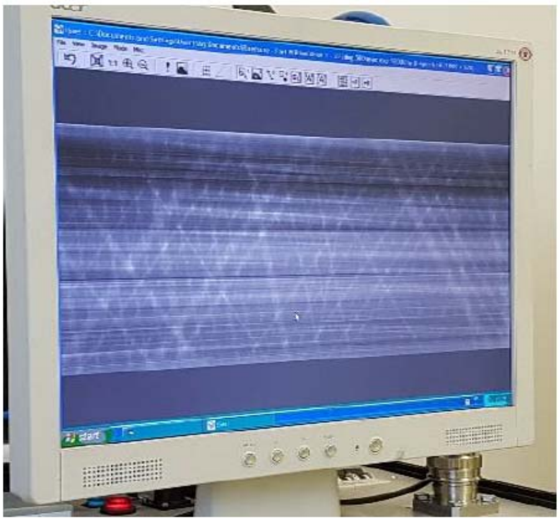


Figure 14: Live radiography image of the riser at 0.06rpm scanning rate indicating internal metal wires mesh structure of the riser.

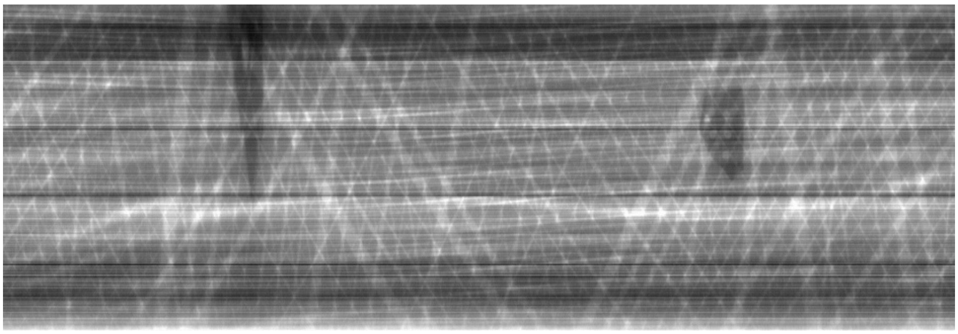


Figure 15: Radiography image of the riser showing artificially introduced defect at 0.03rpm scanning rate.

In order to validate the synchronisation between RiserSure's scanner and detector, a punched hole lead plate image quality indicator (IQI) was created for application to the surface of the riser. This IQI, seen in the radiograph of Figure 15, has a 0.59 (32/54) width to length ratio. This width to length ratio can be measured within the image of the captured radiographs and deviation from 0.59 indicates improper synchronisation.

The RiserSure detector, which has a pixel size of p = 0.4mm, operates exposures at 250ms intervals. It is envisaged that the system will operate at either 500, 750 or 1000ms exposures. A 250ms exposure time would lead to an under-exposed radiographic image due to the thickness of a riser, and anything over 1000ms would result in scan times that are too long in normal conditions. Table 1 lists the computed scanner speed of rotation for the three exposure times based on the trials setup with a source-to-detector distance of 285mm and the single layer of interest is at r = 115mm.

Table 1: RiserSure scanner speeds based on exposure times.

Exposure time [ms]	**Scanner speed [rpm]**	
	Without geometric mag.	**With geometric mag.**
500	0.066	0.060
750	0.044	0.040
1000	0.033	0.030

It can be seen from Table 1 that geometric magnification does have an impact on the theorised scanner speed, requiring it to be 10% slower than if it was not considered.

7. Conclusions

The current system design for deploying the radiography units under controlled subsea conditions proved to be functional, allowing simple operation and requiring only simple human interaction during the assembly stage. During the trials, the effective operation of the scanning system in the sheltered conditions of the Underwater Centre's pier facility was verified, capable to perform precise all-round scanning of the riser at a specified speed and designed to accommodate risers having a diameter of 250±7 mm. Finally, during the trials, it was found that, due to the shadowing of the pier, the lighting system on the camera was insufficient to fully illuminate the assembly whilst submerged.

These trials of the RiserSure system at the UC controlled condition test site, also led to the identification of important requirements for further system improvements, towards the final implementation of a more flexible design that would be adjustable to a multitude of applications in the wider offshore market, and robust enough to withstand real/world subsea scenarios.

Due to the nature and design of some offshore assets, the deployment of the scanning system from these more complex assets is expected to be more complicated and may require remote or at least semi-remote deployment, inspection and retrieval capabilities with as little human interaction to attach to / detach from the riser. Further developments to the system design are therefore recommended, to incorporate a more flexible means of attachment that will minimise hands-on involvement and meet the deployment/ retrieval requirements of various offshore assets (i.e. ROV deployment solutions). In addition, further improvements on the current design of some key elements of the scanner, such as the motor engagement wheel with the rotating ring, are suggested. That would enhance their robustness and reliability whilst in use offshore, where more aggressive environments are likely to be encountered, and where strong currents and general wave movement can expose any potential weakness of the design.

The additional capability of inspecting larger diameter risers (than 250±7 mm) is a key area that should be considered at the overall final design of the scanner, as well. The above is determined by the strength and type of the radioactive source and its capability to penetrate the riser structure. The larger the diameter, and more importantly the overall density of the combined layers, will have a direct effect on the total radiation path and the associated exposure time needed to complete a full scan of the riser circumference. It is anticipated that the riser tool to accommodate frequently used riser diameters would have to accommodate up to 400mm diameter riser. This would require changes to the scanner mechanics as well as radiography aspects.

Furthermore, the important requirements for efficient and safe cable and tether management were identified. Deploying from the UC pier with careful feeding out by hand is acceptable when only deploying the system on sea depths of a few meters. However, to deploy from the topside of an offshore asset and travel tens of meters subsea along a riser, a better engineered solution is required that will not become entangled or damage the riser equipment or the riser itself. The use of an enclosing spreader beam to spread the weight of the equipment and enclose the tethers and cables is of high importance.

Finally, the requirement for a more powerful camera system (i.e. the Spectrum 120HD camera) to be included in the final system design was defined, that will offer superior lightning capabilities and meet deeper water inspections demands.

8. References

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