

A NOVEL APPROACH TO NON-PIGGABLE SUBSEA PIPELINE INSPECTION

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Introduction

The inspection of subsea pipelines, in particular - flowlines and gathering lines – has recently moved into the focus of offshore engineers. Contrary to most long-distance export pipelines many of these lines are unpiggable. While some of these lines can be inspected with tethered internal inspection tools the only inspection options until recently for the majority of the lines were visual testing, CP-surveys and local defect monitoring. With the MEC™-Combi Crawler system and the PECT inspection system it is now possible to gather integrity information to a level of accuracy that can be compared to in-line inspection, but is obtained by external scanning. This level of accuracy permits carrying out defect assessment based on inspection data. Case studies are presented for each inspection technique – Magnetic Eddy Current (MEC) and the Pulsed Eddy Current Technique (PECT) to show how the subsea inspection tools are adapted to fit the specific inspection task.

Magnetic Eddy Current as an Inspection Technique

The idea of **Magnetic Eddy Current (MEC™)**, which has been developed further from the SLOFEC-technique, is to carry out an eddy current inspection under the influence of a DC magnetic bias-field. Eddy current sensing is a traditional method for the inspection of metallic surfaces. Through the introduction of a magnetic bias field, the sensing coils are also sensitive to far-side defects. The idea is shown in Figure 1.

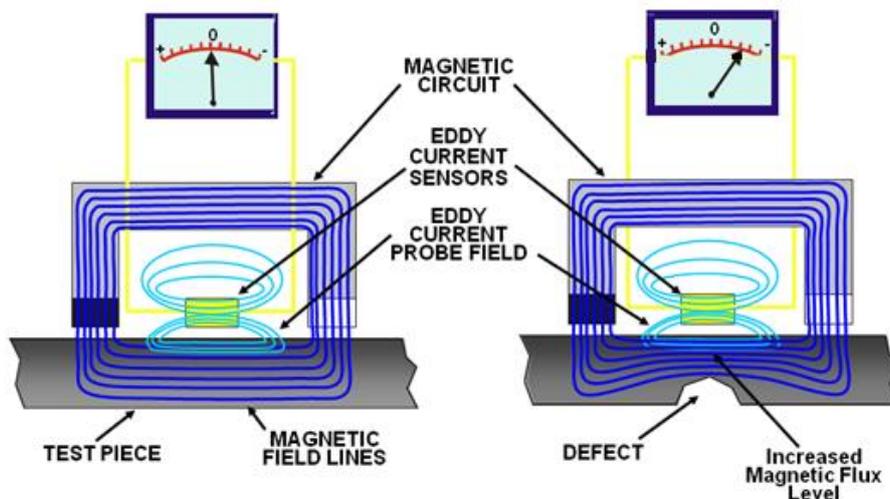


Figure 1: Principle of the MEC™ technology (Magnetic Eddy Current) also known as a further developed technique from Saturation Low Frequency Eddy Current (SLOFEC).

In the presence of a metal loss defect, the magnetization level changes also on the near-side at the defect location. This will lead to a change in the eddy current response, which can be calibrated to the defects size. For near-side defects the method works as a traditional eddy current method.

Again as an eddy current-based method the interaction of the sensor with the pipe surface is via electromagnetic induction. The interaction principle works over distances depending on the relation of sensor size to coating thickness.

In principle an enlarged scaling of the sensor would allow for large distances between sensor and pipe surface. The distance from sensor to ferromagnetic surface is often also just referred to as "lift-off". At least for non-conductive material a coating would act just like an increased air-gap. This is of course the main big difference to ultrasonic testing.

Description of the MEC™-Combi Crawler Tool

The MEC™ Combi-Crawler pipe scanner is designed and built for high performance inspection applications that are tailored to a specific inspection requirement. It can be equipped with laser triangulation sensors to measure the profile of a pipe, with UT sensors to measure wall thickness and eddy current sensors for various applications. The most versatile inspection technique installed on the inspection tool is the MEC™ technique. With these technologies the pipe crawler allows for the detection of internal and external metal loss defects at a rather high scanning speed. Additionally the UT sensor array allows for a corrosion mapping of the covered area.

The scanner head with a MEC™ sensor array covers 180 mm circumferentially, meaning that a number of axial runs are to be taken with overlap to have 360° coverage of the full pipe. For a 6" pipe with ~200 mm diameter this would require four scans to complete the full 360° coverage. Several views of the tool are shown in Figure 2. The UT sensor array also consists of eight sensors. The sensors are staggered to allow for a closer circumferential sensor pitch.

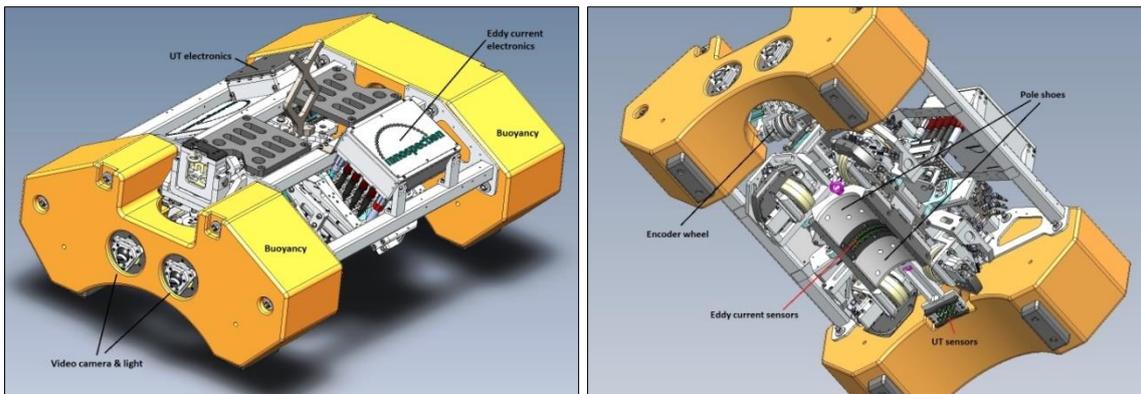


Figure 2: The MEC™-Combi Crawler tool for the inspection of subsea pipelines

The distances driven are measured with an encoder-wheel both in axial as well as in circumferential direction. An umbilical is connected to the tool for supply of electrical and hydraulic power by the ROV. In addition the eddy current and UT signals are routed to a top-side data-acquisition system via the ROV umbilical.

Pulsed Eddy Current Testing (PECT) as an Inspection Technique

Pulsed Eddy Current Testing (PECT) is an inspection technique traditionally used for corrosion under insulation (CUI) screening on carbon steel onshore structures such as pipes, vessels, tanks and spherical tank legs without the need of contact with the steel surface.

PECT is a static technique able to measure spot percentage variations in steel thickness through any non-conductive and non-magnetic material between the sensor and steel surface such as air, insulation material, concrete, plastics, coatings, paint, sea water, marine growth, deposits, oil, etc. PECT is a comparative technique where the percentage variations measured on the specimen are compared with a calibration value which is always assumed to be the full wall thickness.

The PECT measurements can be split in two phases. In the first phase, a current applied to the transmitter coil generates a magnetic field around the probe known as the 'primary field'. The primary field is unaffected by the presence of any non-conducting and non-magnetic materials and penetrates undisturbed through the coating to reach the steel surface below. In this way, the carbon steel directly beneath the transmitter coils is magnetized. Since the carbon steel is ferromagnetic (i.e. it has a high relative magnetic permeability), only the top layer of the steel is magnetized.

In the second phase of the measurement, the current in the transmitter coils is switched off and as a consequence, the primary magnetic field collapses. The changing magnetic field induces electrical eddy currents in the surface of the steel material and these eddy currents generate a secondary magnetic field that reaches the receiver coils of the PECT probe inducing a voltage to this. The magnitude of this voltage as a function of time is referred to as the 'PECT signal'.

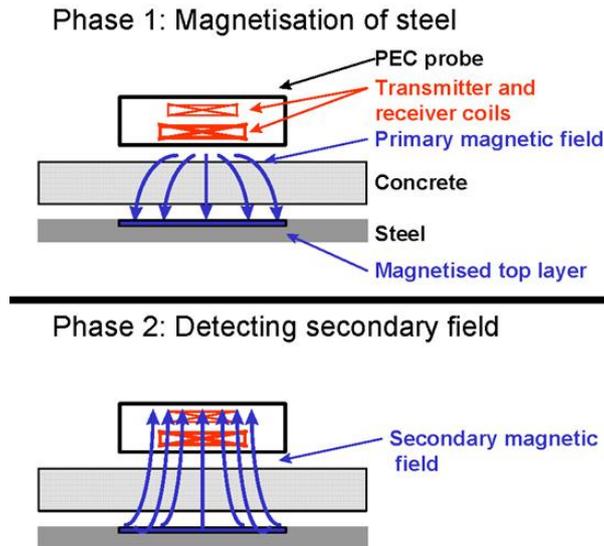


Figure 3: Functioning principle of the Pulsed Eddy Current Technology (PECT)

The PECT signal contains information about the thickness of the steel as described in the following. Initially, the eddy currents are confined to the near surface of the specimen (closest to the PECT probe) but, as time elapses, they travel (or 'diffuse') outwards towards the far surface. As long as the eddy currents experience free expansion in the wall the strength decreases slowly.

However, upon reaching the far surface, their strength decreases rapidly. The moment in time where the eddy currents first reach the far surface is indicated by a sharp decrease in the PECT signal known as the 'transition point'. The time of the transition point is therefore a measure of wall thickness. For example, the earlier the transition point is, the sooner the eddy currents reach the far surface and so the thinner the steel wall must be.

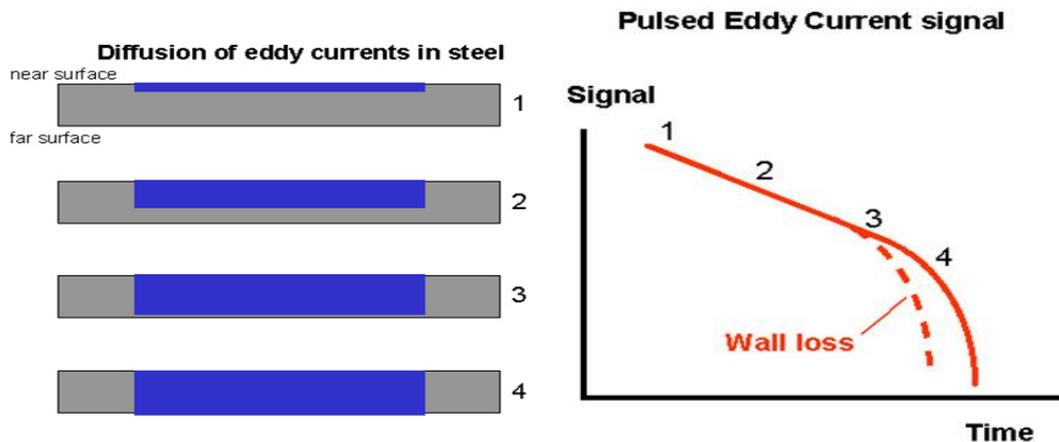


Figure 4: PECT signal response

PECT measures the variations of wall thickness in comparison to a calibration by static time measurement between induced filed lines and returning field lines. PECT takes an average wall thickness measurement over a footprint area and does not require physical contact with the steel.

PECT Inspection Equipment

The ability of PECT to read through large coatings make this technique very versatile and applicable to a variety of scenarios and environments. Innospection has PECT inspection equipment available for utilisation in a dry and wet environment. For subsea applications a semiautomatic scanning ring has been developed to improve inspection performance, in particular timing and reproducibility of the inspection.

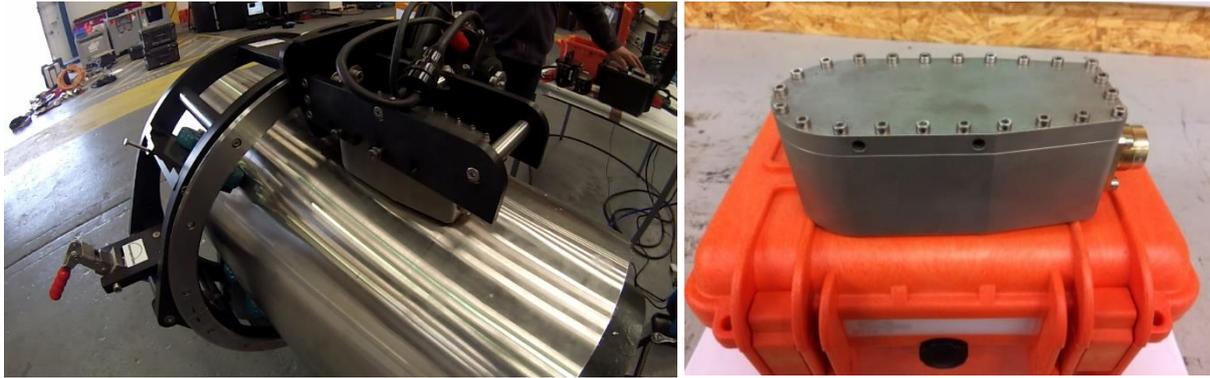


Figure 5: Semiautomatic PECT inspection ring and PECT subsea probe

The ring can be easily deployed by rope access or divers. It is clamped onto the pipe. The electric drive system allows circumferential movements of the probe to be controlled remotely by the operator to enable inspection in well-defined circumferential positions. The probe is connected to a laptop computer via an umbilical. Thus the inspection data can be viewed real time as the inspection takes place. The results obtained from the inspection operation are reported by means of a grid of percent values representing the remaining wall thickness of the specimen versus calibration.

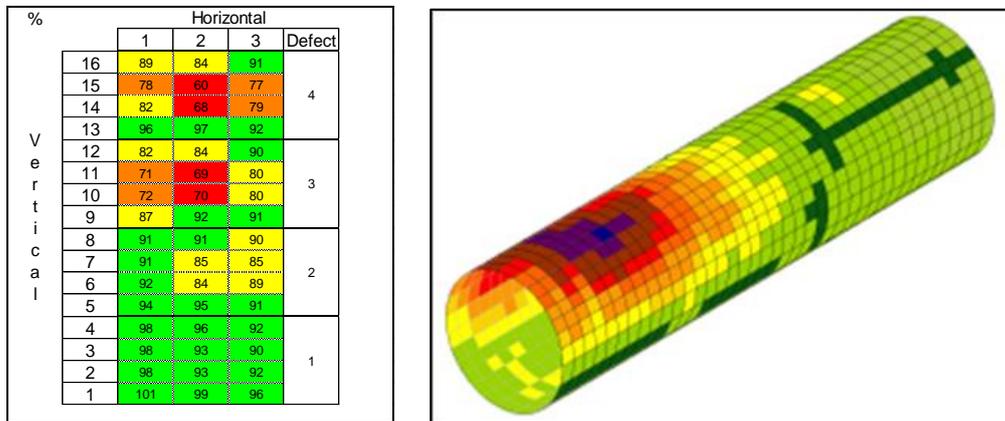


Figure 6: Representation of PECT inspection results

Technology Selection for External Pipeline Inspection

Different technologies are available for corrosion inspection of subsea pipelines from the external. This includes MEC™, the PECT and Ultrasonic Testing (UT). All of them have different capabilities and limitations. Taking this in consideration the following table shall provide guidance for technology selection.

Property of Pipe to be inspected	MEC™	PECT	UT
Pipe wall thickness	up to 30mm	up to 100mm	up to 50mm
Coating type	all electric non-conductive coatings and up to 3mm thick Monel coating	non-metallic coating and insulation including concrete weight coating	3LPP, FBE etc.
Coating thickness	up to 15mm	up to 250mm	up to 3mm
Bends	limited	1.5D x 90°	1.5D x 90°
Inspection speed	dynamic	static (2s per reading)	dynamic
Type of defects	localised external and internal defects and general corrosion / wall loss	general external and internal corrosion / wall loss	localised external and internal defects and general corrosion / wall loss

In cases where more than one of the techniques is applicable it makes sense combining them. The use of a secondary technique allows verifying and confirming defect indications reported with the primary inspection technique. Most of the Innospection equipment is therefore built around the idea of combining different inspection techniques.

Case Studies

To illustrate the inspection techniques and the deployment possibilities of the MEC™-Combi Crawler and the PECT equipment, two case studies shall be presented.

Pulsed Eddy Current Inspection of a Subsea Pipeline

The object of inspection is a 12" reinforced concrete coated subsea gas pipeline. The concrete weight coating had some steel bar reinforcement and was approx. 55mm thick. The inspection operation was part of an assessment for life extension. The pipeline is unviable for internal inspection. As a result, it had to be externally inspected at selected locations utilising subsea capable Pulsed Eddy Current equipment measuring the average wall thickness through the reinforced concrete coating present on the subsea pipeline.

In advance of conducting the subsea inspection work the inspection equipment had to be qualified in dry and wet tests. Artificial defects of different size and shape were introduced in test spools with similar characteristics as compared to the subsea pipeline of interest.



Figure 7: Concrete weight coated test spool (left) and example of artificial defect (right)

The wet trials were conducted in a test tank capturing a volume of 5m³. The setup allowed deploying the subsea Pulsed Eddy Current equipment on the test spool to simulate the underwater environment and scan execution.



Figure 8: Deployment of subsea Pulsed Eddy Current equipment as part of the wet trials



Figure 9: Control Box, data visualisation software and subsea tool control software

The wet trial was successfully completed which allowed initiating the mobilisation of the inspection equipment and team to the field.

The scope of the operation included the inspection of five 12m long sections of the 12" subsea pipeline. The sections of interest had to be dredged in advance of the inspection to create access for the tool. The inspection tool consist of a scan frame including two Pulsed Eddy Current probes which are separated by 180°. The scan frame allows accurate positioning of the probes circumferentially and axially. The inspection tool was lifted overboard the dive supply boat using the deck crane and lowered to the sea bed. An ROV helped positioning the tool on the pipe. After having inspected a length of approx. 1m the inspection tool was lifted and re-positioned to inspect the adjacent section and so forth.



Figure 10: Subsea Pulsed Eddy Current equipment deployed on subsea pipeline

The subsea inspection operation was completed successfully. The results were confirmed by the client in an accessible location using an alternative inspection technique.

MEC™-Combi Crawler Inspection of a Subsea Pipeline

In this project several subsea flowlines had to be inspected that were assumed to suffer from internal channelling corrosion. No inspection had been done so far and the lengths of the lines were in a range of 5 to 10 km. They connect subsea manifolds to a production platform. The pipelines were 6" and 8" diameter. As channelling corrosion is predominantly expected in the 6 o'clock position the full

circumference had to be scanned. The line was coated with a 3 mm 3-layer PE coating. The water depth changed from 250 to 450 m. The wall thickness was $\frac{1}{2}$ ".

Because of the coating, the UT sensors had to be checked for the suitability for this purpose. UT sensors were positioned with a pitch of 9.3 mm and a stagger of 22 mm to allow for higher resolution scanning. The use of MEC™-Sensors in the presence of a PE coating had already been established in earlier projects. A full scale wet-test was carried out in the Ocean-Lab at Newburgh North of Aberdeen. The purpose of such a test is to verify not only the inspection technology, but also the manoeuvrability of the crawler on the pipe.

The MEC™-Combi Crawler was hooked up to a work-class ROV as shown in

Figure 11.



Figure 11: The MEC™-Combi Crawler on site.

Altogether four sections have been selected along the stretch of the pipeline for inspection. One section was typically 6 to 8 m in length. The selected sections were assumed to be representative with respect to the corrosion condition. For instance the elevation high and low points of the line were selected for inspection. In these areas the seabed was removed by water suction. About $\frac{1}{2}$ meter below the pipeline was required to allow for the crawler to reach the 6 o'clock position.



Figure 12: View of the pipe and the seabed after intervention.
The picture is taken from the camera on the crawler.

Because of the closely packed UT sensors the full circumference was scanned with approximately 12-15 scans. This resulted in a high redundancy of the MEC-measurement. In some cases a defect signal was scanned by five different tracks.

The quality of the inspection data depends on the smoothness of the ride over the pipe surface. A good indication of this is the speed profile. After the acquisition of the data speed profiles are investigated with respect to accelerations. A sample speed profile is seen in Figure 13. It shows a rather constant scanning speed of 0.2-0.25 m/s throughout the scan. The complete scanning of a section was achieved within ½ to 1 hour.

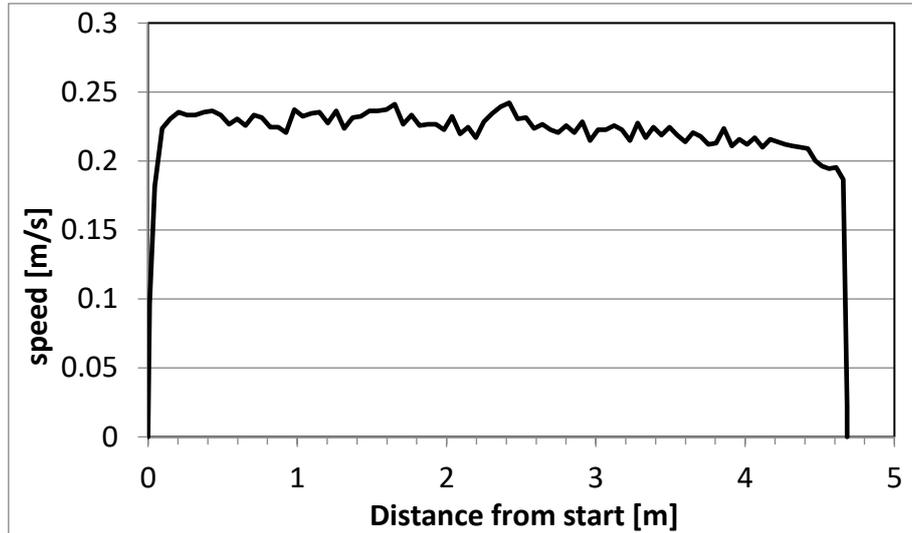


Figure 13: Speed profile of a scan

The results have revealed the presence of channelling corrosion in all inspected sections. However, some sections were more affected than other. Lines of corrosion were visible, very much as expected. A sample report page is shown in Figure 14.

There are four data views altogether. From left to right there is the MEC view on internal corrosion, the MEC-view on external corrosion, the UT view on the wall thickness and the UT view on the sensor stand-off. The internal MEC data shows a line of corrosion at the 6 o'clock orientation often known as "channelling" or "6 o'clock corrosion". These lines of corrosion do not need to concentrate at 6 o'clock. It depends on the flow regime and the water levels in multi-phase pipeline what the o'clock position is. However, the lines will be symmetric to the vertical line. This is what has been found in this inspection. The UT data is more sensitive to the gradual changes, while the MEC-data is more sensitive to localized pitting. In essence they two measurements complement each other.

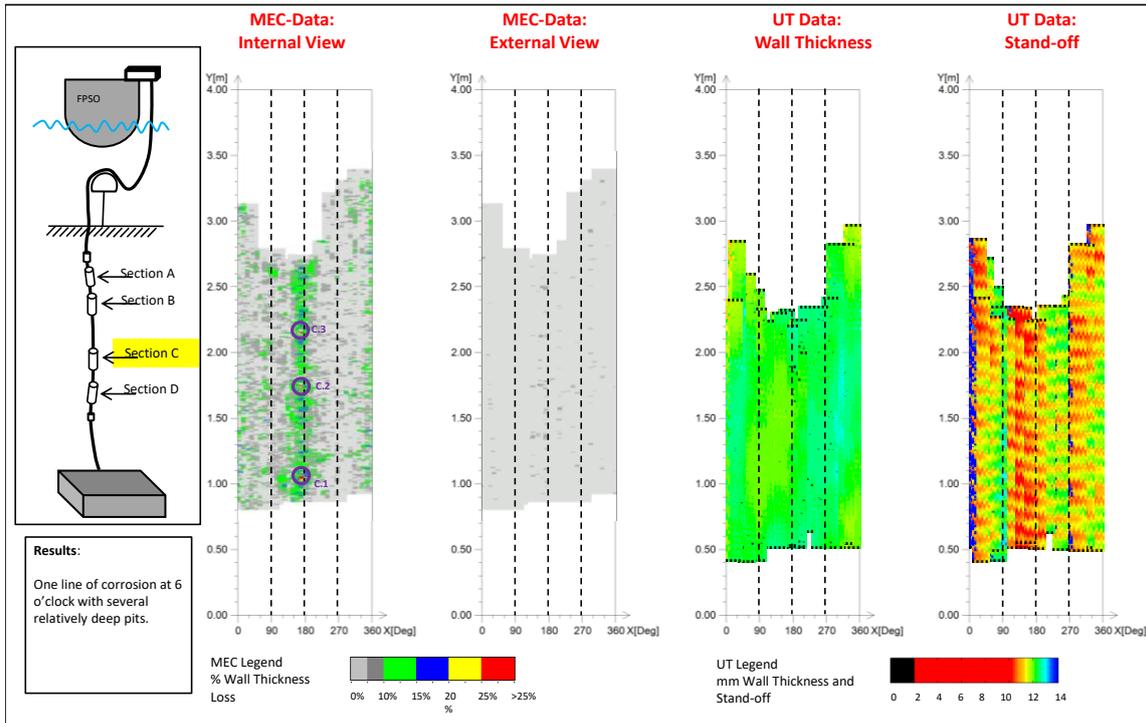


Figure 14: Sample report page for full circumference inspection of pipeline on the seabed

Figure 15 shows another example of the internal MEC data. It demonstrates the level of detail and the location accuracy that can be achieved.

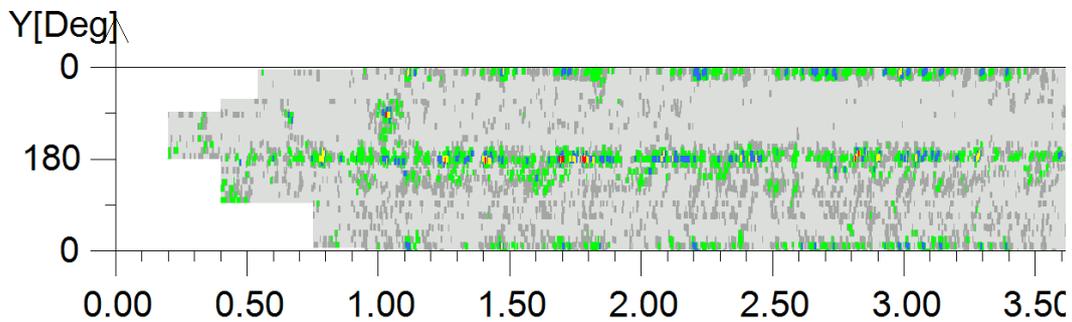


Figure 15: Full view of internal defects with MEC™

Single defects can be reported in terms of defect depth, length and width. With respect to a datum point the location of the defect can be given within cm of the actual location. This is comparable to what an In-Line inspection tool can achieve.

Conclusion

Subsea pipelines need to be inspected just like onshore pipelines. While export pipelines have been inspected with ILI for many years now, a suitable inspection solution for non-piggable flowlines is now also being introduced. These external inspection solutions may not yet be as standardized as ILI is, but the level of reliability of the data is comparable.

Different inspection technologies and tools are available for external subsea pipeline inspection. Technology and tool selection can be made based on the specific inspection task. The presented inspection equipment has successfully been used under very different circumstances for various projects.