

ConaENDI 0102

INSPECTION OF BROKEN WIRES IN FLEXIBLE PIPES USING THE MWM-ARRAY TECHNIQUE

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ABSTRACT

The inspection of flexible pipes in subsea environments has been a topic of interest in recent years, mainly aimed at detecting broken wires in the internal and external layers of the tensile reinforcement. Such ruptures can occur in different regions of the pipe section, mainly due to stress corrosion cracking (SCC) effects. The need to perform inspections in the field for ruptures in the wires below the external insulation layers of flexible pipes led to the testing of the MWM®-Array system from JENTEK Sensors for this type of application. Tests were performed on a flexible pipe sample, where ruptures in the wires were included and inspections were performed with different distances from the sensor to the sample, simulating different thicknesses of external coating. The results obtained with the tests demonstrated a promising capacity of the MWM-Array technique to detect different defects in the tensile reinforcement of the flexible pipes.

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1. INTRODUCTION

The use of flexible pipes has been increasing in recent decades in the Brazilian oil production scenario. Compared to rigid steel pipelines, the use of flexible pipelines can be advantageous, among other reasons, due to their ability to adapt to different configurations and arrangements in offshore systems. This type of structure is composed of several layers of metallic and polymeric materials, each with its specific function, to compose the pipeline and allow its flexibility. Figure 1 illustrates a flexible pipe section with different layers of materials.

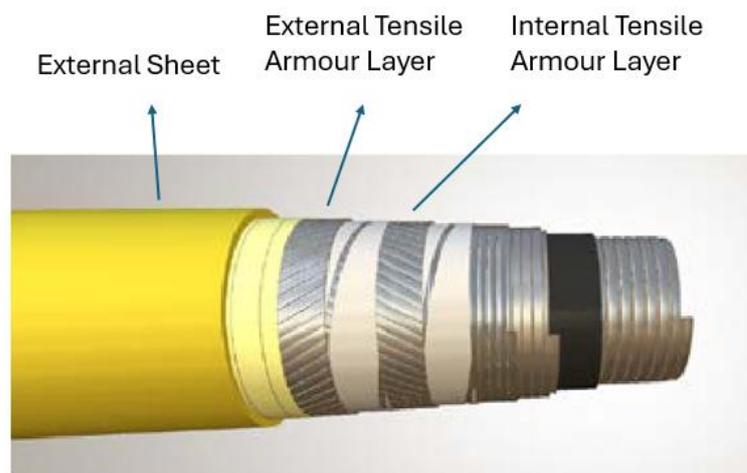


Figure 1: Flexible Pipe Structure. Adapted from: TechnipFMC (1).

The tensile reinforcement wires, whose main function is to resist axial loads, eventually fail due to fatigue mechanisms (in the region closest to the end-fitting) and due to stress corrosion cracking mechanisms caused by CO₂ (SCC-CO₂), which can occur along their entire length. Inspection and monitoring methods sensitive to these damage mechanisms have been studied and some of them have already been applied in field situations, especially for detecting ruptures of tensile reinforcement wires in the region close to the end-fitting. Systems that allow the detection of ruptured wires along the pipelines are still being tested and developed for operation in a subsea environment. One of the possible techniques for inspecting wire ruptures, seeing the failures through the external polymer coating on the flexible pipe, is the MWM®-Array technique from JENTEK Sensors. This technique allows the inspection of metallic structures through a solution based on pre-computed physical models, which present the results through the GridStation® Software. The potential of the technique, already proven for structures with CUI (Corrosion Under Insulation) cases (2), led to the adaptation of this system, both of the sensors and of the software and its configurations, to inspect broken wire structures in flexible pipes (3).

The main objective of this development is to detect broken wires and evaluate the effectiveness of the system in different configurations. The following sections present the MWM-Array system used for the inspection of broken wires in flexible pipes, describe the sample inspected and the defects and clearance conditions tested. Subsequently, the results and conclusions obtained for each condition tested are presented.

2. MWM-ARRAY TECHNOLOGY

MWM-Array sensors are electromagnetic eddy current sensors that have one or two rectangular drive coils for excitation of an electromagnetic field and linear arrays of secondary inductive sensing elements for reading the response. The design of the sensor's rectangular coils defines the depth of penetration of the electromagnetic field, allowing sensors to be customized according to the type of pipe and its coating thickness.

During measurement with the MWM-Array sensor, a sinusoidal current is applied to the drive coil, generating a magnetic field in up to three frequencies simultaneously. This field generates eddy currents when in proximity to conductive materials. The magnetic fields associated with the generation of eddy currents add to the field generated by the drive current, and this resulting field is measured through the sensor elements (4). Through the voltage generated in the sensing elements, properties of the material being inspected and defects present in it can be detected.

JENTEK's measurement technology has the advantage of accurately predicting sensor response through pre-computed models, which assume model parameters such as magnetic permeability, conductivity, sample thickness, sensor geometry and sensor distance to the conductive material (Lift-off). For the flexible pipe inspection, the lift-off considered is the distance between the external wire layer and the sensor (includes the insulation thickness and the gap between the insulation and the sensor). Sensor responses are converted into physical or geometric properties of the inspected material through Grids (5), processed in the GridStation software. The grids used for measurements on flexible Riser samples consider pre-computed lift-off and magnetic permeability parameters. Figure 2 shows an example of the grid used for measurements on the Riser sample, where points measured at different lift-offs of the same sample are shown.

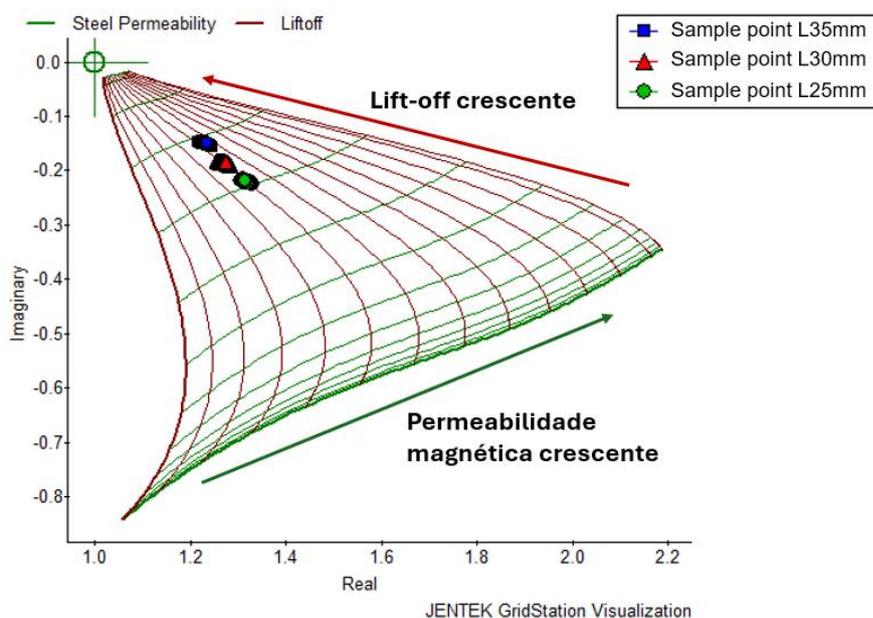


Figure 2: Grid with magnetic permeability and lift-off properties.

The equipment used for testing flexible risers is the GS9000 (6), an impedance equipment from JENTEK Sensors with 79 parallel acquisition channels. This GS9000 configuration allows the use of up to 4 sensors with 19 channels each, providing complete coverage along the circumference of the riser sample. Considering that the acquisition is done entirely in parallel between the channels, the inspection time is greatly reduced when compared to technologies that require multiplexing between their channels to achieve the same coverage area.

Figure 3 shows the equipment and sensors used for the tests. The GS9000 instrument was adapted to facilitate its use in enclosures for use in submerged environments. The inductive sensors were manufactured in flexible material, enabling measurements in different sample configurations and curvatures. During acquisition, the measuring equipment is activated and controlled through the GridStation software installed on a laptop connected to the equipment.

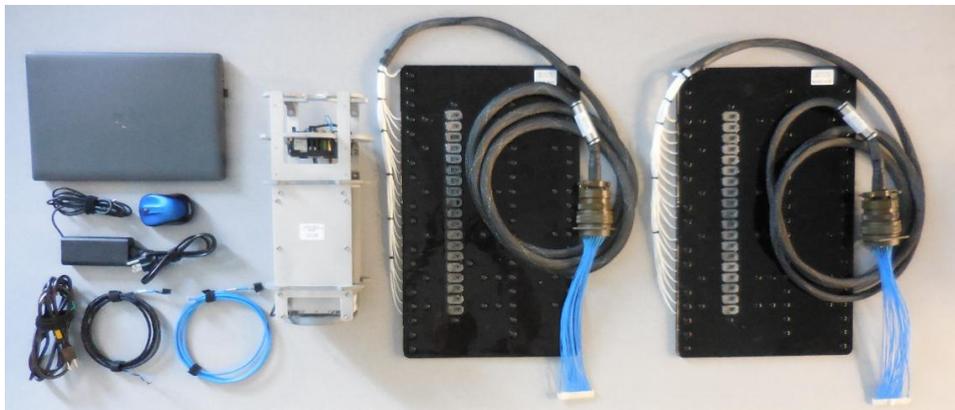


Figure 3: GS9000 system with inductive sensors used for measurement.

To perform the tests, sensors were installed in a manual scanning structure, allowing different sample lift-off configurations. The GS9000 equipment was housed in a protective structure, facilitating its use and connections. The system (equipment and sensors) assembled for use can be seen in Figure 4, as well as scheme of four 19-channel array sensors providing full circumferential coverage of the pipe for scanning. The scanning process can be performed axially at a relative fast speed for the inspection (in the order of 10cm/s). The scanning process does not require bias fields for the inspection, making the scanning more practical.

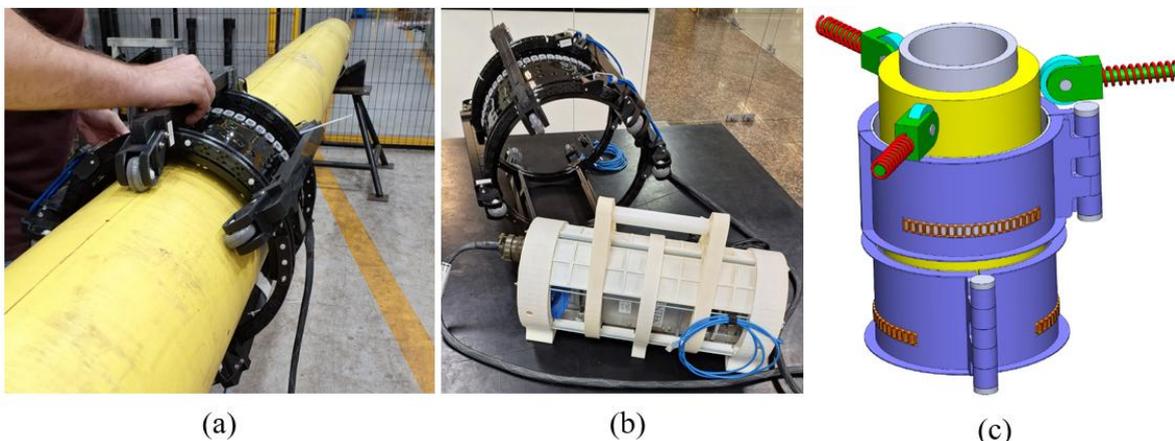


Figure 4: (a) Scanning process. (b) GS9000 system mounted. (c) Scheme of four 19-channel array sensors providing full circumferential coverage of the pipe for scanning (3).

3. TEST SETUP

The tests for inspection of broken wires were performed on a flexible pipe sample taken from the field, with no history of field ruptures present in the analyzed section. The sample has an external diameter of 266 mm and has two layers of wires in the tensile reinforcement. After the external tensile reinforcement, there is an external coating of 10 mm thickness. The test region is 4m long. The tests with the MWM-Array system were performed by scanning axially the sample, keeping the sensor over the external coating without contact.

To simulate different clearance conditions, and the possible presence of thermal insulation after the external coating, tests were conducted with different clearances from the sample. Considering the total distance between the metallic conductive layer of the external tensile reinforcement and the sensor surface (total lift-off considered), the test configurations were 17 mm, 30 mm and 42 mm of lift-off. Figure 5 shows the different lift-off configurations used during the tests.

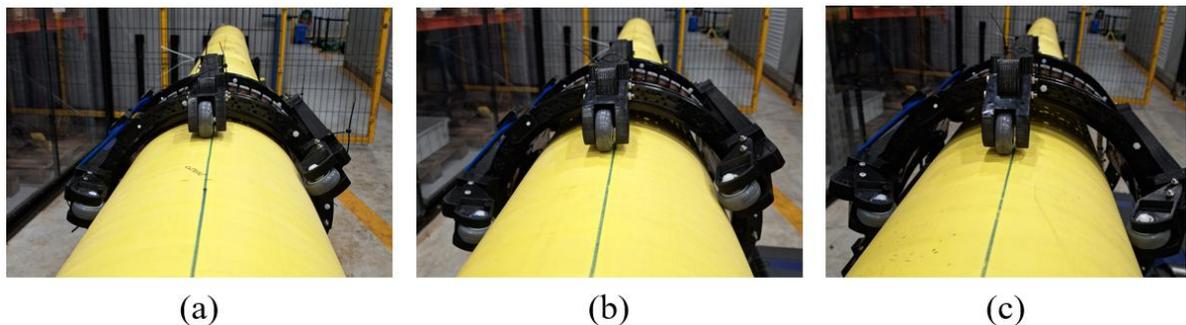
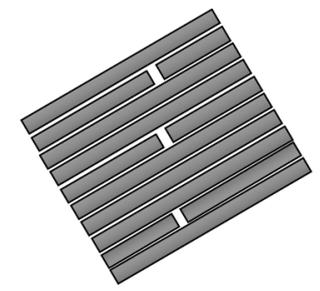
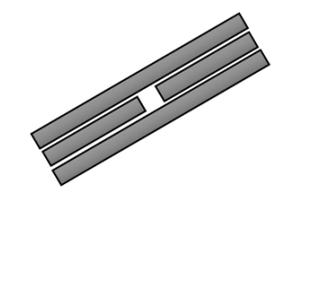
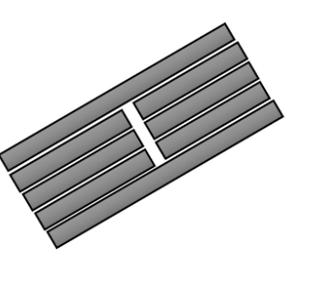


Figure 5: *Lift-off* configurations tested (a) 17mm (b) 30mm (c) 42mm.

For the test, rupture defects were introduced into the external tensile reinforcement through small openings in the external sheath. In total, different defects were introduced, distributed in 3 distinct regions of the sample. The defects were manufactured with a small cutting saw, to cause minimal interference with neighboring wires. The regions with introduced defects are located at positions 1.8 m, where 3 defects were introduced in spaced wires, at position 2.5 m, where one defect was introduced, and at position 3.7 m, where 3 defects were introduced in adjacent wires. Table 1 shows the configurations and positions of defects tested and images.

The sensor used has 19 channels, an arrangement that has the coverage capacity to read approximately 320 mm of the external circumference of the pipe sample. During the test, the sensor advanced over the regions with defects in order to enable detection using mainly the central channels of the arrangement.

Table 1: Tested Defect Settings

Position	Region 1 – 1.8m	Region 2 – 2.5m	Region 3 – 3.7m
Description	3 spaced defects with 5mm opening	1 defect with 10mm opening	3 adjacent defects with 5mm opening
Settings			
Image			

4. PRELIMINARY RESULTS

The preliminary results of the measurements performed on the flexible pipe were obtained by evaluating the variations in the magnetic permeability property in the regions with the defects present. The measured magnetic permeability is obtained directly from the GridStation software with the settings developed for the application in the flexible pipe. Figure 6 shows the magnetic permeability measurement obtained between channels 9 and 12 of the sensor for the case of 17 mm of lift-off, where the regions with defects present can be identified through the dashed red lines. It can be seen that depending on the extent of the defect and the region it occupies, more than one channel will be able to detect its presence. This feature also makes it possible to differentiate between regions with more severe defects.

Figure 7 shows the magnetic permeability map (C-scan) measured for all channels in the coverage area. Due to the complexity of the structure of the wire layers of the flexible Riser tensile reinforcement, intense variations in properties are perceived by the sensor in a large part of the structure, which may occur due to differences in properties between the wires that make up the tensile reinforcement.

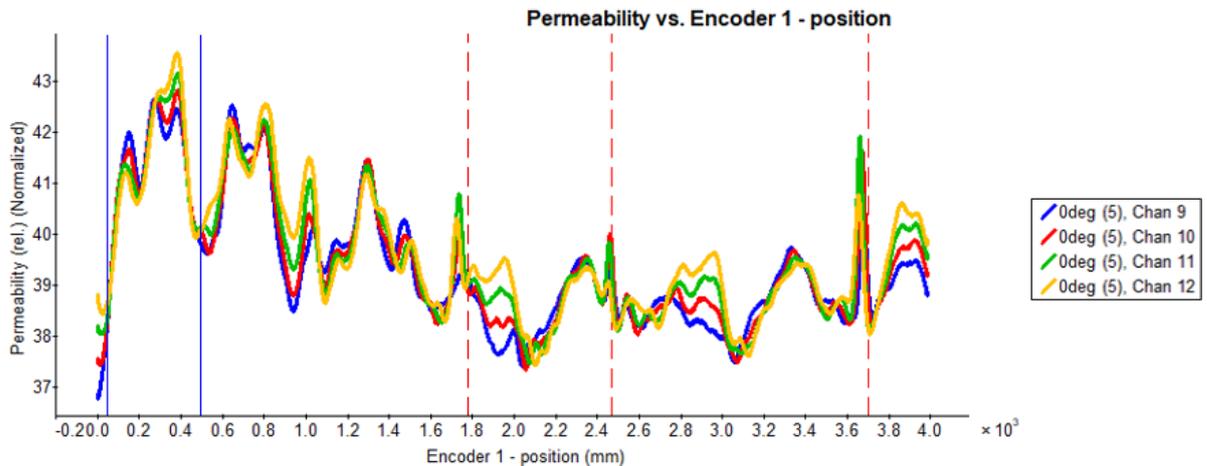


Figure 6: Magnetic permeability between channels 9 and 12 for measurement with 17mm Lift-off.

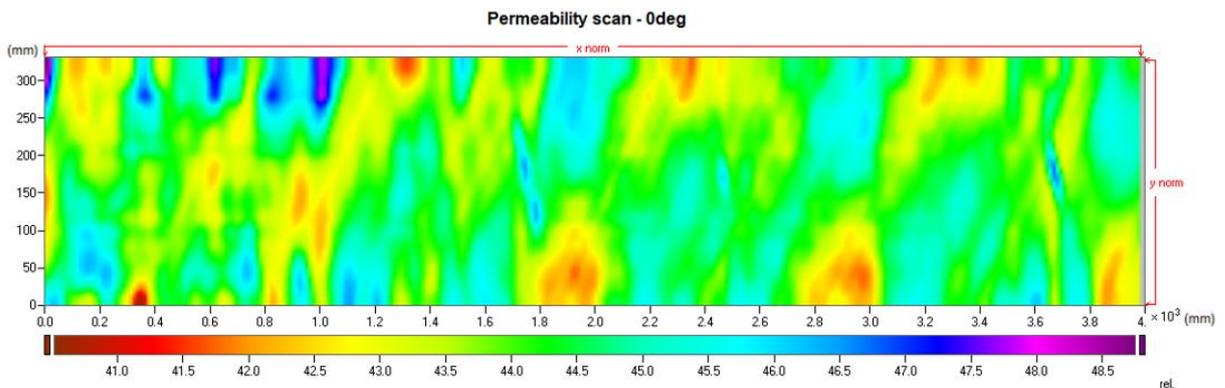


Figure 7: C-Scan magnetic permeability measurement with 17mm Lift-off.

To transform the magnetic permeability response into indications of the position of defects, post-processing of these signals was performed, aiming to remove background variations that do not correspond to defects present in the sample. It is interesting to note that this type of processing does not require baseline measurements of the sample in the same region prior to the presence of the defect. From the measured signal, an estimate of the original state is made, and then the signal that does not correspond to the presence of defects is removed.

Figure 8 shows the results after processing the magnetic permeability for the measurements performed at lift-offs of 17 mm, 30 mm and 42 mm. It can be seen that for the 17 mm lift-off condition, it is possible to differentiate the 3 defects in region 1 and the defect in region 2. The 3 adjacent defects in region 3 form a single indication, with greater amplitude and greater channel coverage. For the 30mm and 42mm lift-offs, region 1 with 3 defects showed an indication for two of the closest defects and another for the furthest defect. The defects in region 3 again showed a signal with greater intensity. In relation to the largest lift-offs tested, some artifacts remained as processing residues, however, they did not prevent the indication of the measured defects.

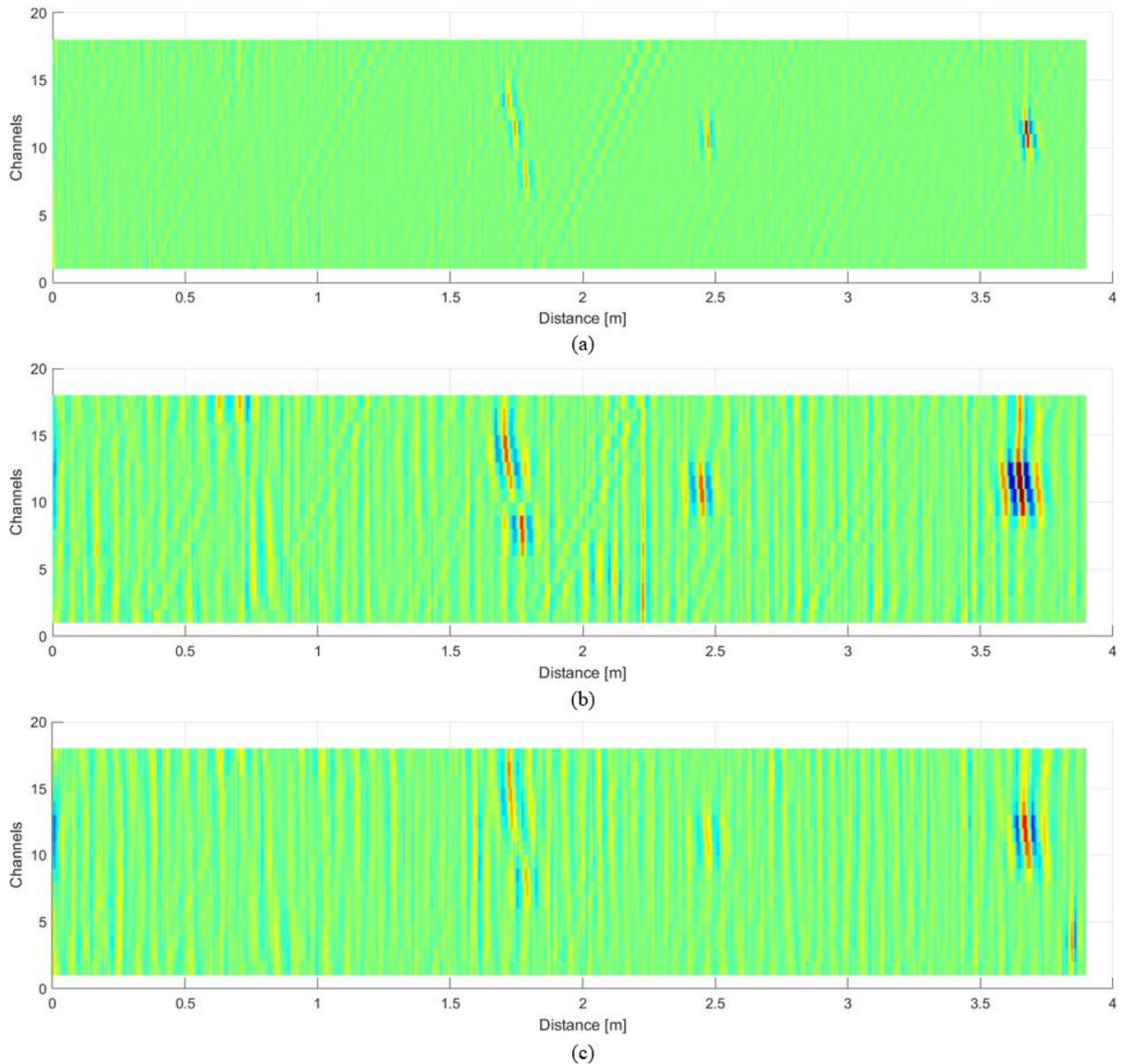


Figure 8: Results after processing the magnetic permeability signals for the tested Lift-off configurations (a) 17mm (b) 30mm (c) 42mm.

Figures 9, 10 and 11 below show the processed results from another perspective for better visualization of the indications obtained for each Lift-off.

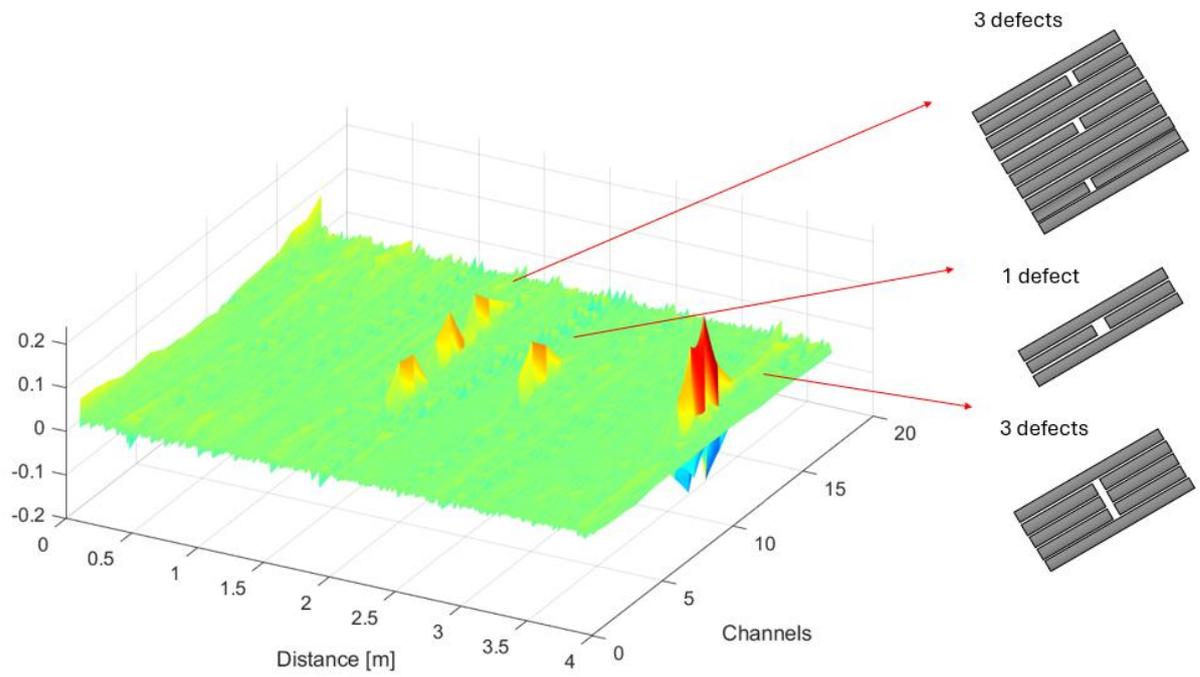


Figure 9: Results after processing the magnetic permeability signals for 17mm Lift-off.

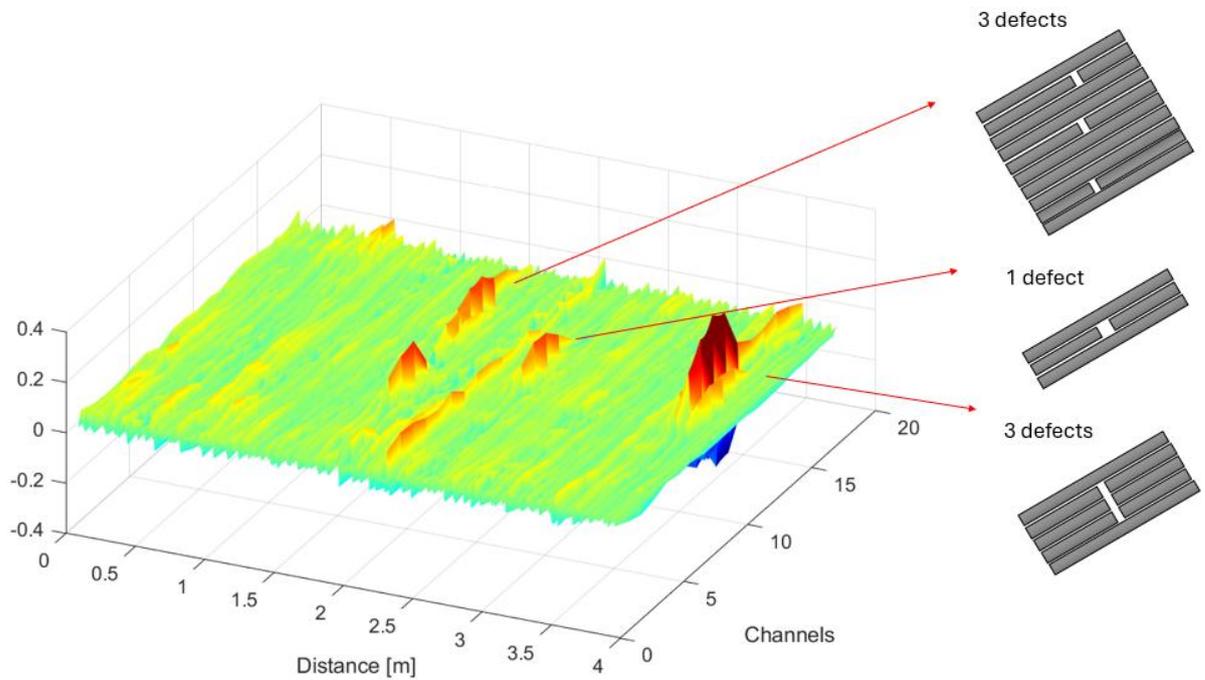


Figure 10: Results after processing the magnetic permeability signals for 30mm Lift-off.

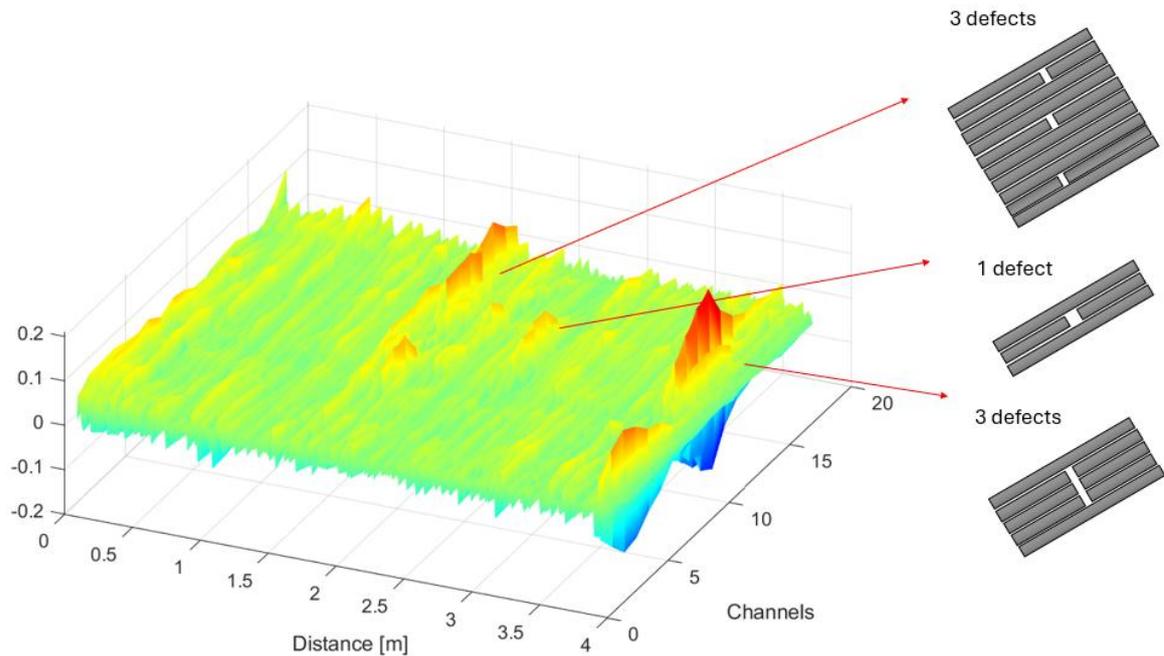


Figure 11: Results after processing the magnetic permeability signals for 42mm Lift-off.

5. CONCLUSION

JENTEK Sensors' MWM-Array technology for inspecting broken wires in flexible pipes was successfully tested on a pipe sample considering three different lift-offs in relation to the external tensile reinforcement: 17mm, 30mm and 42mm. For all measured cases, the defects were accurately indicated in the positions in which they were found during scanning with the sensor. The measurements performed with 17mm of lift-off were those that presented the clearest results for each of the defects, due to the greater proximity of the sensor to the sample. The technique proved promising for inspecting broken wires in flexible pipes also for cases simulating the presence of polymeric insulation coatings in the pipe, as indicated in measurements performed at 30 mm and 42 mm of lift-off.

5. ACKNOWLEDGMENTS

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