CALIBRATION METHODS AND ACCURACY IN DETECTING DEFECTS IN FLEXIBLE RISER PIPE

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Introduction

In electromagnetic non-destructive testing a proper means of calibration of defect signals versus actual defect size is quite important. Contrary to ultrasonic pulse-echo methods this is not an obvious method, but requires explicit development work. In the field of MFL-pigging this procedure is known as “defect sizing” or “grading”. For metal-loss type defects these methods are well established, even though the details usually remain proprietary knowledge. The object of inspection is always a rigid steel pipe and hence the expected types of signals are limited.

When the concern is the inspection of a different type of pipe like flexible pipe, the task is completely different. Not only do the types of defects change, but so do the signals and the analysis procedure.

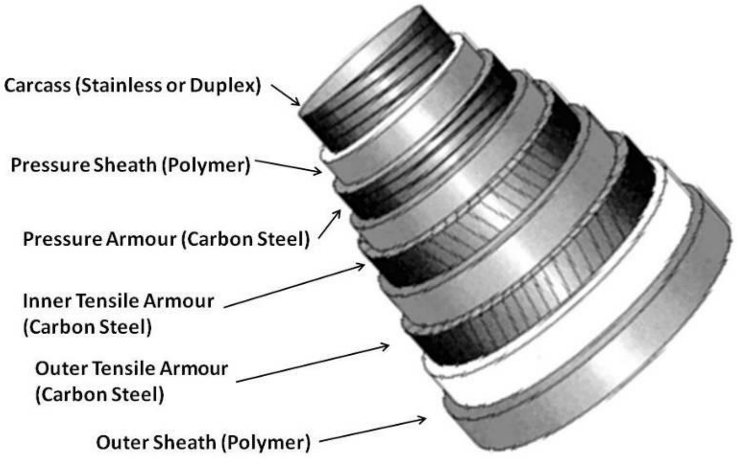

Figure 1: Typical set-up of a flexible pipe used as a riser.

In the following external inspection of the layers of flexible pipe will be discussed. In particular the two tensile armour layers are of interest. They consist of wires with a thickness of typically 4 mm thickness and a width of 10 to 15 mm. They are made of carbon steel of high strength. The orientation of the wires towards the axis of the pipe is typically 35º for riser pipe.

SLOFEC™

The MEC-FIT™ tool uses a method based on Saturation Low Frequency Eddy Current (SLOFEC™). Some aspects of this method in conjunction with the inspection of flexible pipe have been described in the previous paper (ref. PPSA 2011).

In essence the SLOFEC™ technique uses eddy current sensors in combination with a magnetisation of the pipe. Surface effects will be measured by a regular eddy current effect. The magnetisation leads to different permeability levels of far-side defects on the near side. This will also be picked-up by the eddy current sensors. Hence near-side and far-side defects can be detected. Defects in the inner armour layer will act as far-side defects. Any material that is not conductive will act just like air. Hence, an outer polymer layer represents nothing but a larger sensor lift-off.

Artificial defects versus typical natural defects

The problems of flexible pipe are manifold as is their application and the layer configuration. Flexible pipe used as riser is under cyclic load and may suffer from fatigue in particular in the outer-most layer. Hence, the detection of cracking is of interest. Outer sheath damage may lead to water ingress and a potential of corrosion again in the outer layers. Sour service on the other hand may lead to corrosion from the inside, if H_2S permeates through the pressure sheath into the inner layers. Many different types of defects have been reported.

In general sizing/grading methods are based on referencing signals to defects of known size. Due to a lack of natural defects of precise size, artificial defects are produced. Artificial defects have been produced into solid steel pipe as long as there have been testing methods. In particular for MFL-testing it was found that the profile of a defect is important. When introducing artificial defects into a flexible pipe the problem of multiple layers becomes relevant again.

Defects in the upper layers

Putting artificial defects in upper layers is still relatively easy. A portion of the PE outer sheath has to be cut away. It was found to be of advantage, if the cut piece is not too large. The PE-layer is not bonded to the inner layers. If too large a section is cut, the remaining parts will bulge out. It will then become difficult to put the cut piece back. This is important to mimic a real flexible pipe surface.

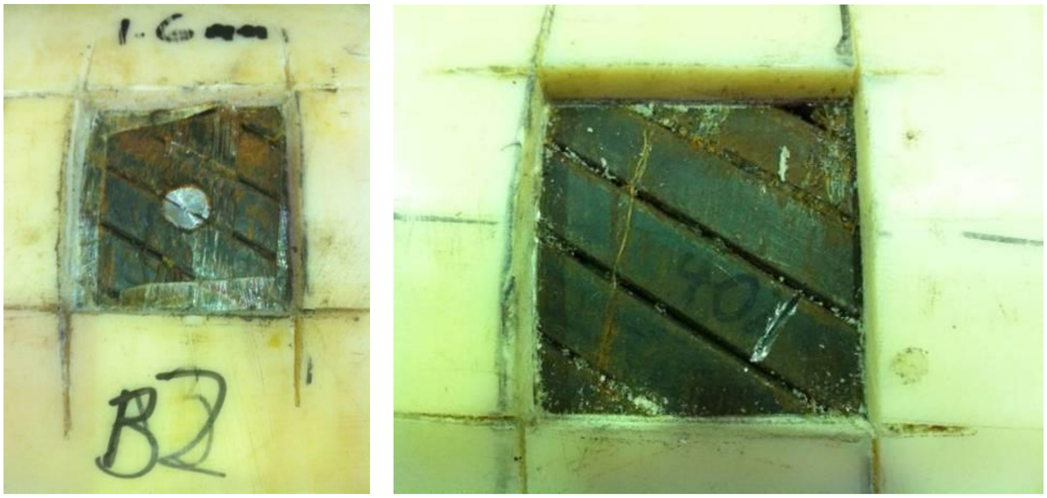

Figure 2: Artificial defects in the outer layer. A flat bottom hole on the left and a crack-like defect on the right.

Defects in deeper layers

There are several methods to put artificial defects into deeper layers. The key is not to damage to outer-most layer. One method is to cut out a larger area of the outer layer completely, to put defects into the inner layer and to tick-weld the outer layer back wire-by-wire. This can be tedious, but yields a high quality inner defect. It has to be considered, that the tick welded wires will also yield a signal, so the cut-out area has to be large enough.

Another method is to drill from the opposite side into the pipe and introduce metal loss effects from the inside. This method suffers from the problem of inaccurate defect depth. The idea and the resulting through holes on the opposite side are shown in Figure 3.

Figure 3: Obtaining internal metal loss defects by drilling holes from the opposite side into the inner layer.

A third method is to drill into the second layer from the outside and use a wire gap that is large enough. In most unbounded flexible pipes the wires are not fixed but can be moved to a certain extend. A gap of some 5 mm can be achieved. This is enough space to cut a slit into the inner layer. Later the wires in the upper layer can be moved to cover the defect. This is shown in Figure 4.

Figure 4: Rearranging layers allows introducing small defects into inner layers.

The issue of defect classification

If different degradation mechanisms are present and all of the resulting defects generate signals in the inspection process, the correct classification of signals becomes relevant. Different defect types lead to different risk assessment results and repair considerations. This is why prior to assigning a size to the defect, the classification has to be done. This is a problem well know from in-line inspection. In MFL inspection corrosion type defects as well as indentations yield a signal. This is easily distinguished. However, this signal classification needs to be done first. Only signals classified as metal loss will then be further graded for size evaluation.

The process for signal evaluation in MEC-FIT is somewhat similar. Also, similar to MFL inspection, the process of defect classification of often more important for the quality of a report than a correct size estimation.

The classification is often done based on the analysis of the signal itself as well as context information. For signal analysis typical pattern recognition methods can be applied. The context information is more difficult to establish. Context information can consist of knowledge of exact pipe configuration, operating conditions, experience in forensic analysis and an understanding of the degradation mechanism.

The relevant features for classification in Eddy Current Testing and also MEC-FIT are in particular the phase of the signal (the inclination in the complex impedance plane), the amplitude and the area of the loop and the orientation (sequence of up/down). Figure 5 shows too different loops, the first originating from a far-side defect the other from a near side defect. In this case the signals are obtained from a rigid steel pipe. They are obviously at different phase angle, but also the second opens up wider.

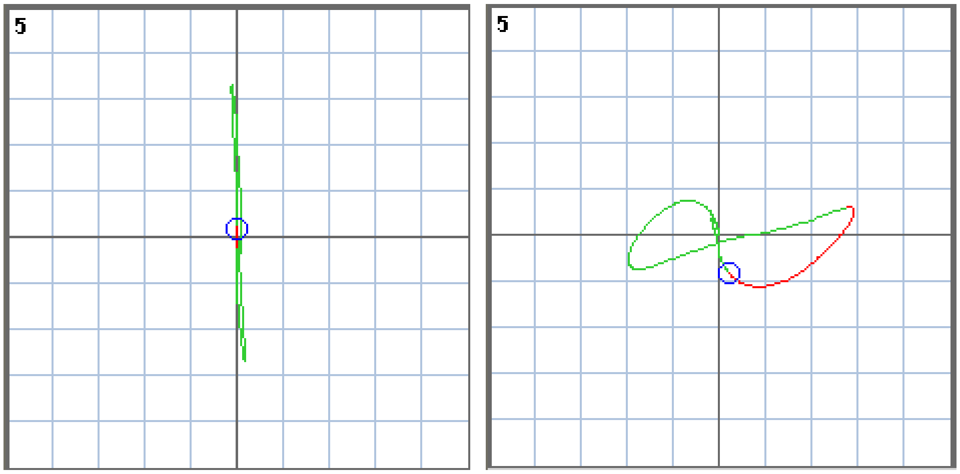

Figure 5: Evaluation of Features in Eddy Current loops; Left a far-side metal loss and right a near-side metal loss are shown.

For the testing of flaws in flexible pipe the same type of parameter are used to evaluate the type and size of the defect. These methods now have to be reestablished and appended. Figure 6 shows a crack-like defect on the outer tensile armour layer on the near side. Signal is quite repeatable and is characterized by the orientation of almost upright. The sequence of signal peaks (down-up) and the fact that is hardly changes with magnetization level.

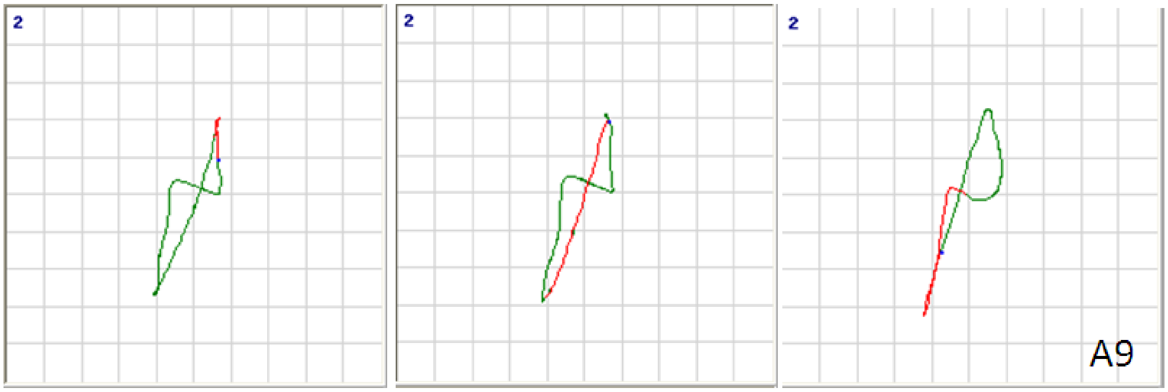

Figure 6: Three signals of a near-side crack-like defect.

As an example of context information Figure 7 shows the scans of a complete pipe. Most of the signals show a stripe structure running at a fixed (35º) angle. Obviously this originates from a wire gap in the outer wire layer. A single signal of one sensor at one position would not reveal the true origin. The structure can be filtered out by the setting of phase discrimination angles. For flexible pipe it is also a good reference for setting the phase angle.

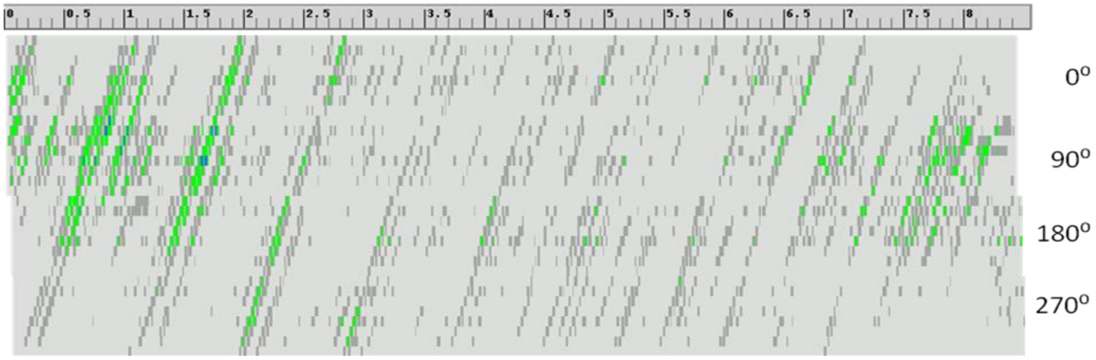

Figure 7: The contour of the signal from scans of the full circumference of a flexible. Obviously many signals originate from the wire structure.

For defects found in the inner layers, a signal can only be obtained by magnetising the wires. Without magnetisation the defect will remain undetected. This is a good method to distinguish the two defect types. If the signal does not disappear with the magnetisation turned off it will originate from the surface. Of course, effects of remanence have to be considered. The remanent magnetisation levels found in the steel of flexible pipe wires have been found to be rather small. An example of a cut wire in the second layer is shown in Figure 8.

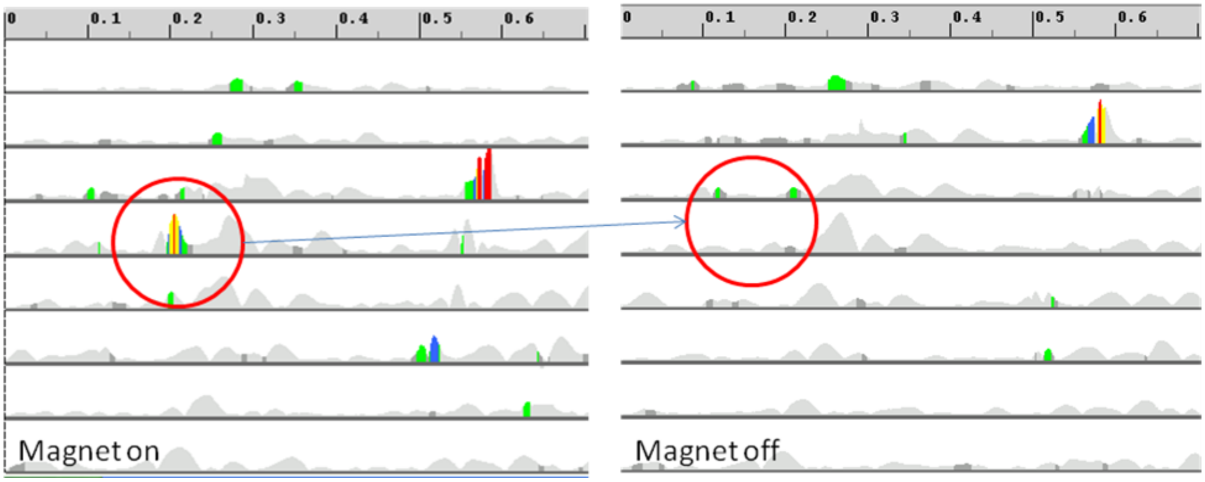

Figure 8: The encircled defect disappears with the magnetization turned off. This indicates an internal defect.

In general the signal increases with increasing magnetization. A peculiar feature of SLOFEC™-based inspections is that the magnetization does not need to be as high as in MFL. MFL requires a magnetization close to saturation. In SLOFEC™ an intermediate magnetization (change of permeability is maximum) is desirable. With higher magnetization the signal may even decrease again. The signal level has been evaluated for different magnetization levels. The MEC-FIT™-tool uses a rotary magnet to set the magnetization level [1]. An integrated Hall sensor allows for setting a predefined level. This can be calibrated to yield an (approximate) level of magnetization in Tesla. Figure 9 shows the result for the inner defect of Figure 8.

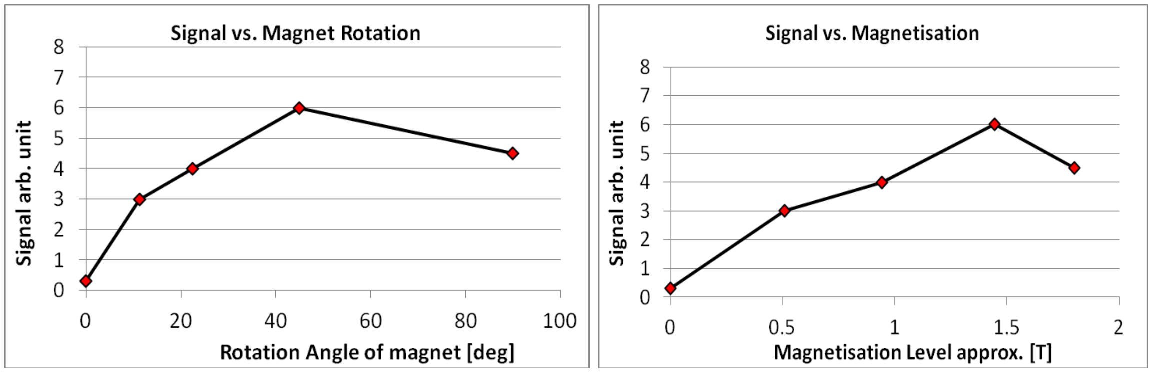

Figure 9: Signal strength vs. level of magnetization for an internal wire defect. Left side shows signal versus rotation of magnet, Right side shows magnetization level converted to Tesla.

The right of Figure 9 shows that the maximum signal level is sometimes obtained at magnetization levels slightly lower than maximum. This is a typical behavior for far-side defects in thin walled rigid pipe.

Calibration on different defect types

Once the signal can be attributed to a unique origin a sizing method can be applied. This is usually based on artificial defects and in a simple form is a calibration curve of defect signal versus defect size. It is known that in methods implying the magnetisation of the specimen, a simple calibration curve by signal amplitude is often not sufficient. For crack like defects, however, a relation “amplitude to defects size” can often be established. Figure 10 shows a curve of amplitude versus depth for flat bottom holes. The signals are obtained for two defects of different size. One is cut only into a single wire; the other extends over three wires. Here the defects width becomes an important parameter. This is very comparable to MFL and required a certain lateral resolution.

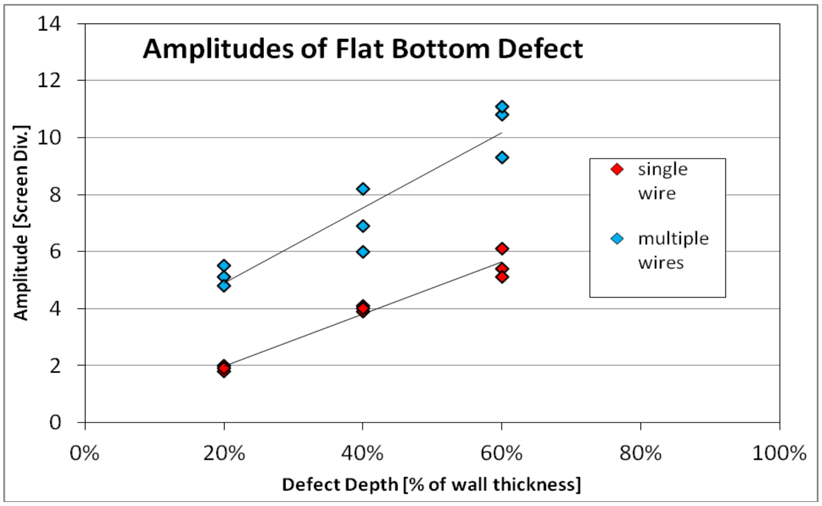

Figure 10: Amplitude vs. Defect size

Deployment methods

There are basically two methods for the deployment of the tool. For the inspection of a riser near the splash-zone, a deployment from top-side with the tool hanging on a rope is most advisable. Figure 11 shows the tool designed for this operation. The large yellow piece is the buoyancy to reduce the weight in water. In the center the magnetisation unit and the sensors are visible. An arm will clamp around the pipe and the tool is driven by hydraulic motors. The motors allow for axial and transverse motion of the tool along the pipe. For a 6 Inch flexible riser approximately four scans are required for complete coverage.

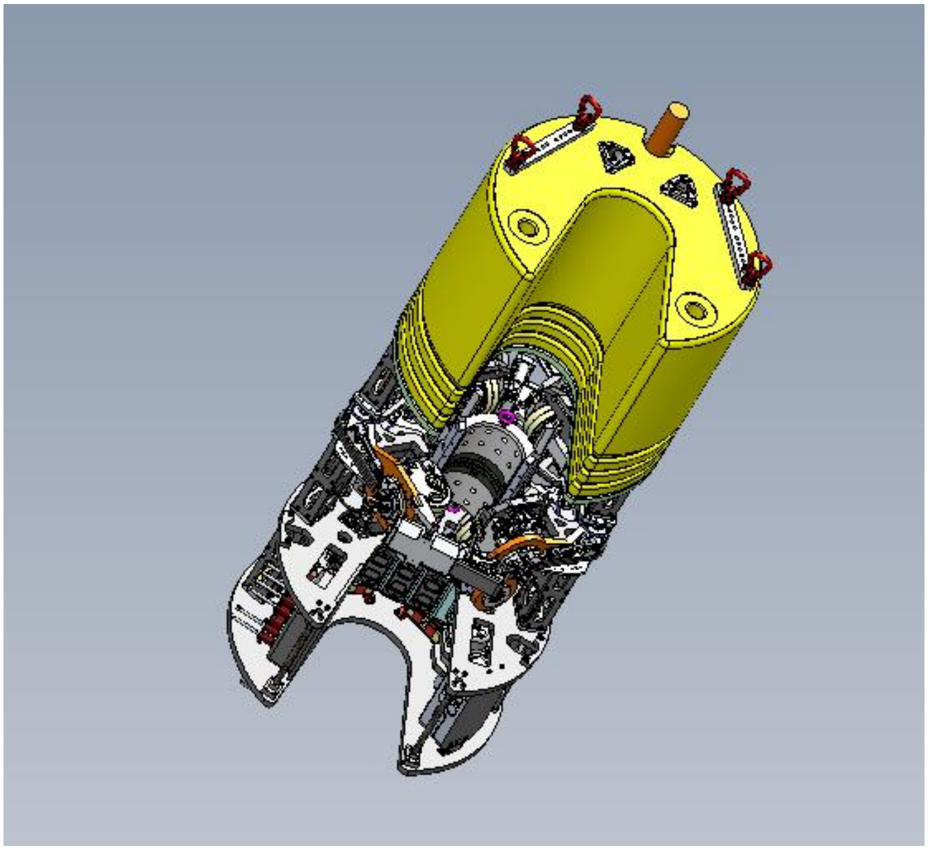

Figure 11: The MEC-FIT™-tool for the deployment from top-side.

For the inspection in deeper waters, as well as for the inspection of flow-lines, the deployment by ROV is most useful. The tool will be attached to an ROV.

Conclusion

Various kinds of defects can be detected in flexible riser pipe. The technique is rather sensitive and hence a proper defect classification scheme was set up. The analysis of the data is quite complex and requires many parameter and signal components to be investigated. One of the parameters is the magnetisation level. This, for instance, will allow distinguishing internal and external defects. With the proper defect characterisation methods, the MEC-FIT™ is a suitable tool for flexible pipe inspection.