MAGNETIC EDDY CURRENT (MEC™) AS A NOVEL TECHNIQUE FOR THE INTERNAL INSPECTION OF CRA-LINED PIPE

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Abstract

CRA-lined pipelines, i.e. pipes with an inner pipe of a corrosion resistant alloy inside of a ferritic steel pipe carrying the hoop stress, pose a challenge to inspect with conventional in-line inspection technologies. Existing UT technology is not able to inspect through the interface of a CRA and a ferritic steel component. Additionally, current MFL technology is not able to sufficiently magnetise the ferritic steel pipe in order to inspect this type of pipe.

The current contribution investigates the possibility of Magnetic Eddy Current (MEC™) to carry out such an inspection. A prototype internal inspection tool has been devised. Several types of sample defects have been produced into the ferritic steel carrier pipe as well as into the CRA-inner pipe. The defect types anticipate the integrity issues that an internal inspection tool would need to address. Several pull tests under controlled speeds have been carried out. The results are presented. Influences of tool speed, magnetisation level and eddy current parameter are investigated. Special attention is drawn to the distinction of different defect types.

The MEC™ technology was found to be a suitable inspection technique for CRA-lines pipes. This is achieved through several adaptations for this particular task. The technology may also fill other existing inspection improvement opportunities, like the detection of small volumetric features or the inspection of heavy walled small diameter gas pipelines.

Introduction

Cladded and CRA-lined pipe has been in use in the Oil and Gas industry for a long time now. The main purpose is to transport hydrocarbon with high contents of corrosive components. Hence they are mainly found in upstream sour service. The idea is to use an inner pipe or layer of a CRA (Corrosion Resistant Alloy) to avoid internal corrosion and to use an outer layer of ferritic steel (carrier pipe) to carry the hoop stress. The alternative would be a pipe of full Duplex or CRA material. However, such a pipe is more expensive as the required volume of the more expensive CRA material is much higher.

Two principally different methods of manufacturing are common today. In the first pipe type the CRA-layer is metallurgically clad to the ferritic layer. This is achieved with different processes, one being the cladding of the CRA layer onto the ferritic steel slab before producing the final pipe. The other method is mechanical bonding. As there is no metallurgical bond between the two metals in the final pipe it is called lined pipe. This is of course not to be confused with the lining of pipes with an inner polymer coating. The process often consists of a CRA pipe to be inserted into a ferritic steel and then to expand it into the inner diameter of the carrier pipe. The CRA pipe is shorter than the carrier pipe. At the ends the inner CRA layer is produced with a weld overlay. At the ends the layer is thus metallurgically bonded even for this type. The main reason for this production method is to ensure that the annulus is not open to the atmosphere and no water ingress is possible. Amongst others this allows for proper welding of the pipe.

The in-line inspection of a pipeline of CRA lined or clad pipe has remained a challenge for existing ILI technologies. The limitations in applying existing ILI inspection technologies strongly depend on the configuration of the CRA layer. For ultrasonic wall thickness measurement the metallurgically clad pipe does not present a problem. As the difference in acoustic impedance between the two steel layers is small a full transmission of the UT pulse is present and a normal pulse-echo method can be applied [1].

Only the presence of crevice corrosion (see below) may present a problem. In case the CRA layer is intact, but the carrier pipe suffers from metal loss on the internal side, the rear-wall echo will always be from the far-side of the CRA layer, hence not delivering any information on the carrier pipe. For lined pipe this effect is always present. UT wall thickness inspection of the lined pipe will thus only inspect the CRA layer.

For MFL-based inspection the situation is different [2]. The presence or absence of the bonding does not constitute a difference. There are mainly three problems:

- Naturally a DC magnetic method does not deliver any information about the non-magnetic CRA layer.
- The effectiveness of the magnetisation of the ferritic carrier pipe is strongly reduced because the magnetic poles cannot get close to the carrier pipe.
- The magnetic field sensors are lift-off from the ferritic steel surface. The obtained signals are much weaker.

For a configuration of a 3 mm CRA layer and a 20 mm carrier pipe in an 8" outer diameter pipe, this would effectively render the pipe difficult to inspect with MFL. In configurations with lower wall thickness and larger diameter, MFL will see some defects. The typical defect detection specification would be reduced.

As such, there is opportunity to investigate and develop an alternative ILI technology that can inspect the full wall thickness of a CRA clad or lined pipe. This contribution will investigate the suitability of the Magnetic Eddy Current technology to address this application.

Magnetic Eddy Current Technology

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.

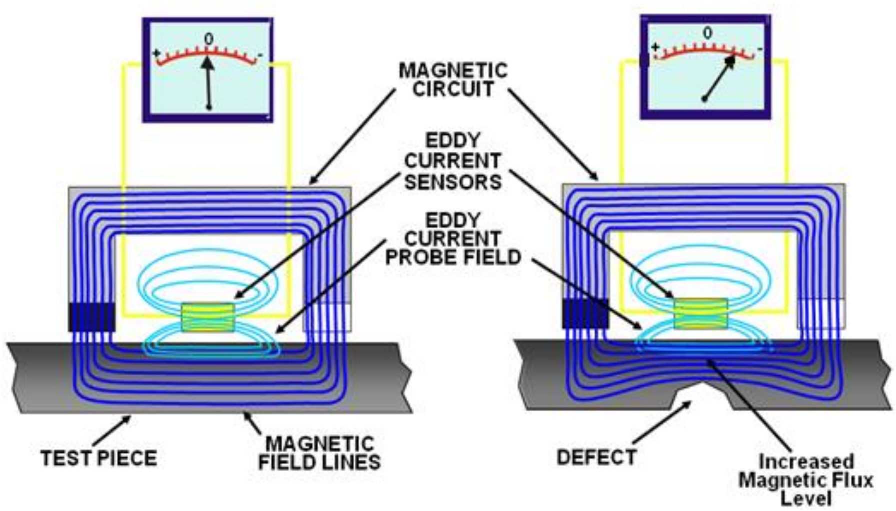

Figure 1: Principle of the MEC™ technology (Magnetic Eddy Current) also known as a further developed technique from Saturation Low Frequency Eddy Current (SLOFEC™).

In the presence of a far-side 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 defect size. For near-side defects the method works as a traditional eddy current method.

Test Pipe and Types of Defects

Two 12 m lined pipes have been made available to Innospection. The pipe has the below technical characteristics:

	Carbon Steel carrier pipe	CRA-liner
OD	8.625” (219 mm)	
ID		6.765” (171.8 mm)
Thickness	0.812” (20.6 mm)	0.118” (3 mm)
Material	X65	825 Incoloy
Pipe Type	Seamless	Long seam welded

Internal overlay welding and subsequent grinding completes the internal layer at the pipe ends.

External defects

This defect type consists of metal loss on the external side of the carbon steel as shown schematically in Figure 2.

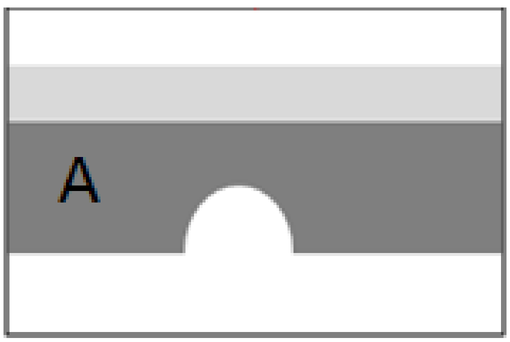

Figure 2: External defects

The depth ranges from 10% of the carbon steel wall thickness to 80%. The spherical defects are machined by mechanical cutting. The diameter of these spherical defects ranges from 3 mm (0.125”) to 24 mm (~1”). All defects are round-bottomed holes.

Erosion-type defects

Defects of this type represent erosion defects. They show a rather smooth change in thickness of the CRA-layer. Altogether three defects of this kind have been produced using electric discharging (EDM). The depth ranges from 20% to 60% of the liner wall thickness.

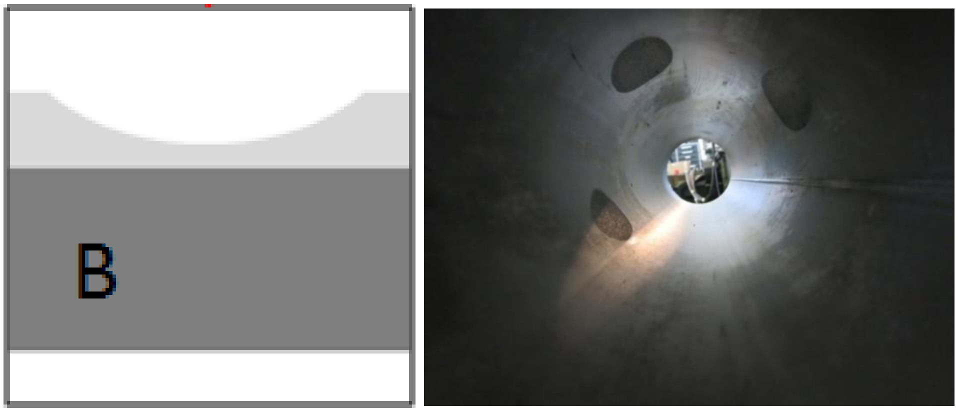

Figure 3: Defects of erosion type

Girth weld cracks

A typical girth weld with Inconel was produced and crack-like defects were placed into this weld. They are also machined with EDM. The resulting depth is roughly checked with a feeler gauge. A sample is shown in Figure 4. The depth ranges from 0.5 mm to 1.5 mm. Some cracks were produced into the base material of the CRA. All cracks are oriented in the circumference, which is the expected orientation of cracks in pipelines in operation.

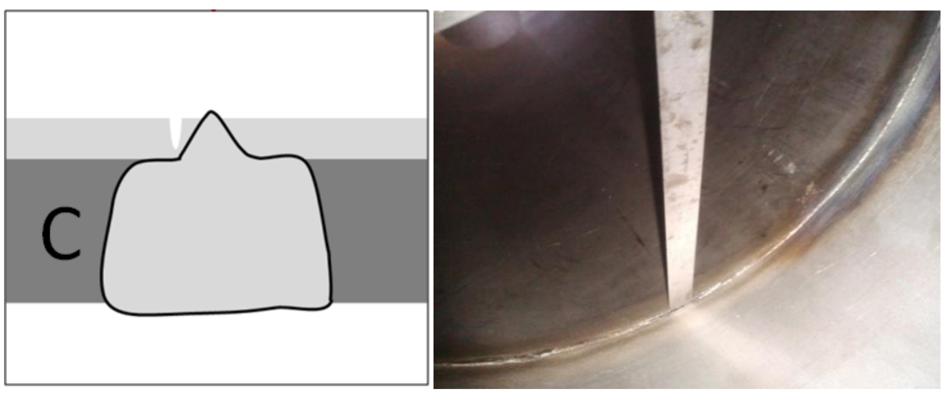

Figure 4: Crack-like defects in the CRA-weld

Internal Carbon Steel crevice corrosion

These defects are most difficult to produce. They consist of metal loss defects on the internal side of the carbon steel. With the CRA-layer intact, they are not visible, neither internally nor externally. The configuration is shown in Figure 5.

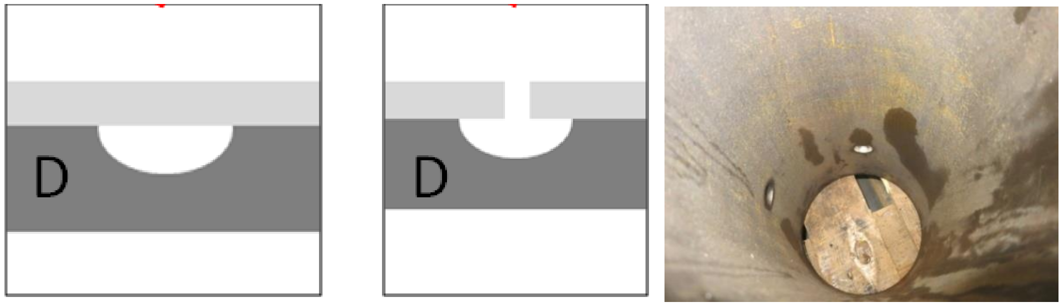

Figure 5: Crevice Corrosion Defect Type

To produce these defects the CRA-layer had to be removed. This was only possible for smaller section of the pipe. Sections of 400 mm length were cut and the liner was pressed out. To be able to press it out a small cut of a width of about 3 mm had to be put into the liner internally. The defects are then internally produced in the carbon steel with EDM and the CRA-liner is placed back. The liner is then tick-welded to the carrier to ensure that it is fully expanded and does not move, when the internal tool is pulled through. Hence, after placing the liner back, there is no annulus between liner and carrier pipe. One defect has a 3mm hole in the CRA-pipe right above the metal loss in the carrier pipe.

Prototype Inspection Tool

Magnetic Circuit

The magnetic circuit was calculated with 3D-Finite Element Calculation (FEM) using the software package MagNet of Infolytica. It was evident from the beginning that the magnetic circuit has to generate a high level of magnetic flux. The size of the specific used NdFeB-material magnets was bespoke.

The results of 3D-modelling are shown in Figure 6. The model is a quarter of the full circumference. This is sufficient due to the symmetry of the magnetising unit. It is also modeled with a carbon steel plate and CRA layer of the respective thickness.

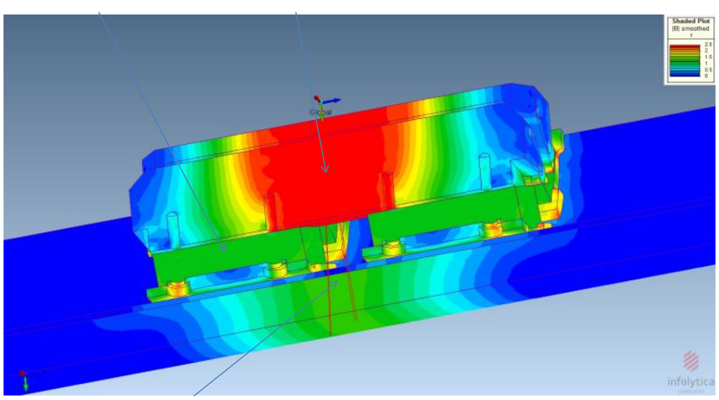

Figure 6: Magnetostatic modeling of the magnet unit.

The modeling results of the magnetisation in the steel wall is comparable with other MEC™-scanners and therefore considered to be sufficient. It is considerably less than the typical requirements of an MFL-Scanner.

In addition a calculation was done with the magnet unit moving at a speed of 0.5 m/s. This is in the lower range of a possible pipeline inspection speed. The results are shown in Figure 7. As expected the magnetisation is dragged behind the magnet unit to some degree. The level of magnetisation at the far-side, however, is not affected. The highest field level is found at a few cm (~1") behind the position of the sensor. The magnetisation level on the near side is increased due to the motion. The two effects usually result in an increase of detectability of near-side defects and a reduction for far-side defects. At a speed of 0.5 m/s this does not seem to be too dramatic.

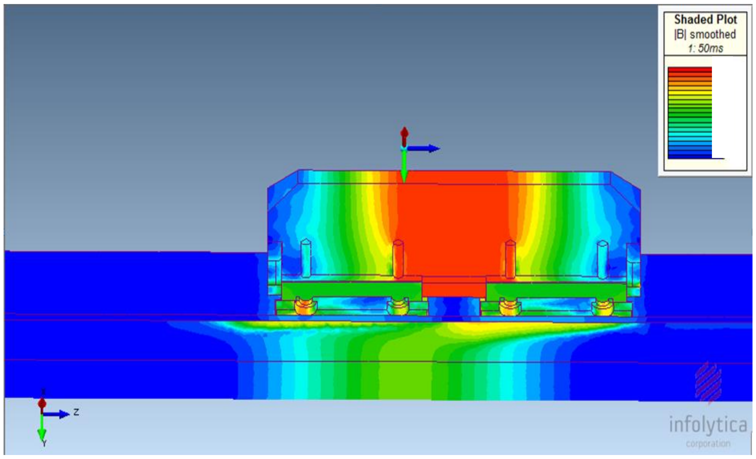

Figure 7: Modeling result at a velocity of 0.5 m/s

Sensors

Three different types of sensors are tested. They are shown in Figure 8. Two of these are regular MEC™-type sensors shown in the left and center of Figure 8 and in addition a multi-differential crack detection sensor (right).

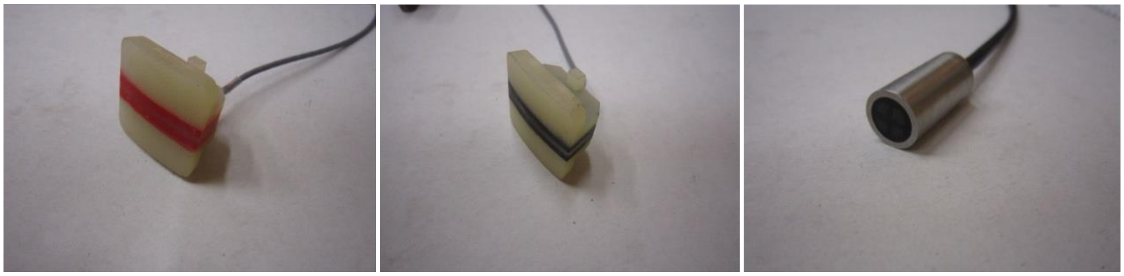

Figure 8: Sensors to be tested for signal quality and detection capabilities

The MEC™-type sensors are mounted in the magnet unit. They also have a certain capability of detecting cracks, but are optimised for metal loss. The MEC™-type sensor can be run in differential and in absolute mode. This results in two independent sets of data. The crack detection sensor (right) does not require a bias magnetic field. It will detect surface breaking cracks.

The prototype tool and set-up

The prototype tool consists of two bodies, the magnetisation unit and an additional sensor carrier as shown in the right of Figure 9. The sensors are connected to a data processing unit via an umbilical as seen on the right of the image. In the picture the tool rests in a tray for easy launching and receiving. A cone-shaped cylinder simplifies the tool entry into the pipe.

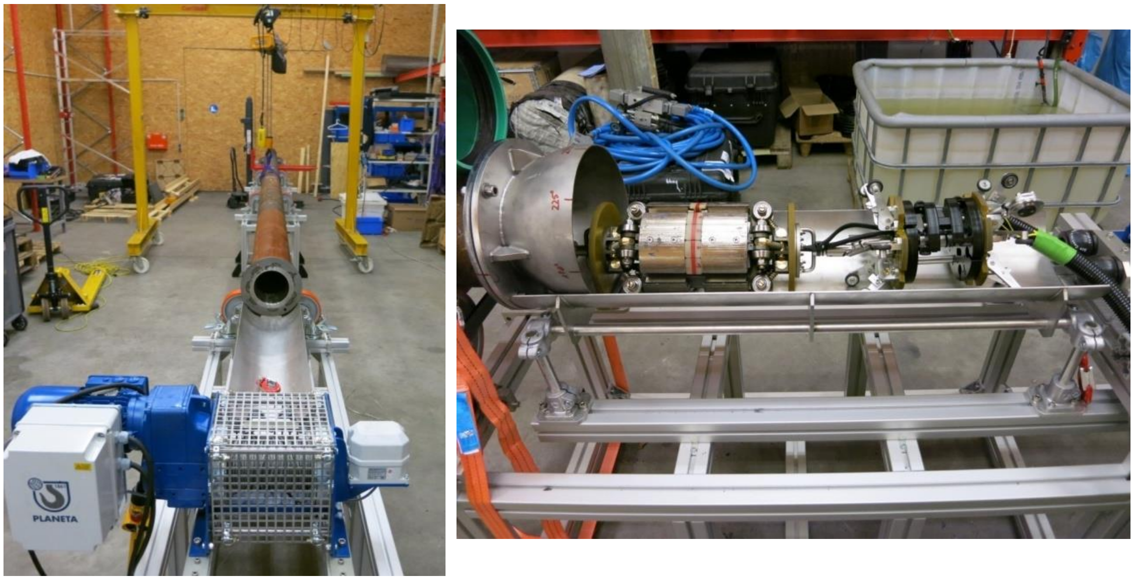

Figure 9: Left: Set-up of the test spool, Right: Prototype inspection device

Results

The results are shown in Figure 10 to Figure 15 as eddy current amplitudes in a C-Scan-like format. It has to be stated, that this only shows a small part of the obtained information. Eddy current signals are complex impedance values and are thus usually depicted in a 2D-plane. For the sizing and defect type classification the full information is exploited. For the sake of simple depiction the amplitude in selected phase sectors is shown in a bespoke color code in the following pictures. This only gives an impression of the detection capabilities.

External metal loss

Figure 10 shows the signals of the external defects. The signals have been obtained with the MEC™-Sensors in differential mode. The 10% defects have not been detected in this mode. For defects of smaller diameter (3mm), deeper defects are difficult to detect. This is somewhat expected, as the volume of missing metal is very small.

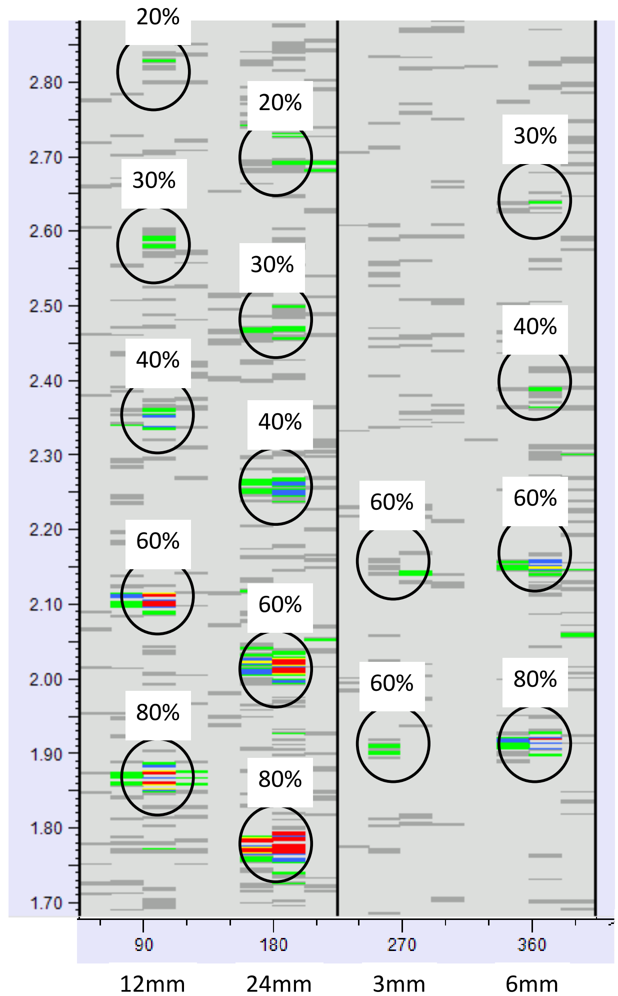

Figure 10: Data screen shot of external defects

Note that the two defects shown for 3 mm diameter are indeed 60% in depth. The limit for detection of such small diameter is somewhere in the range of 25% depth and does not seem to depend much on defect diameter for defects exceeding 6 mm.

Cracks

In principle, crack-like defects are also visible with MEC™-type sensors. Figure 11 shows the data screenshot of a base material crack-like defect. This signal is obtained with the second MEC type sensors in differential mode. The weld signals are grayed out, as they require an extra treatment.

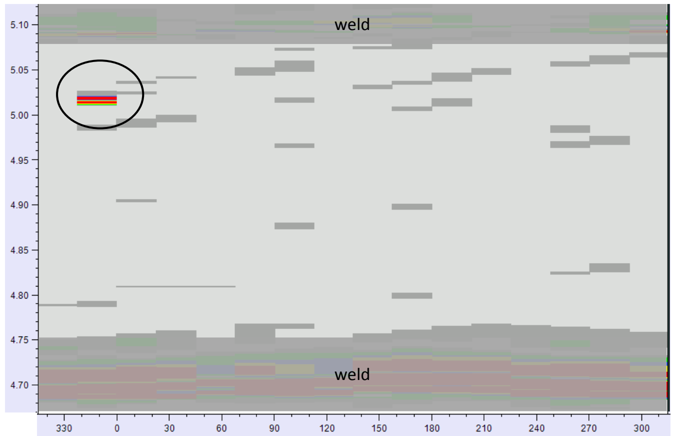

Figure 11: Signal of a base material crack-like defect.

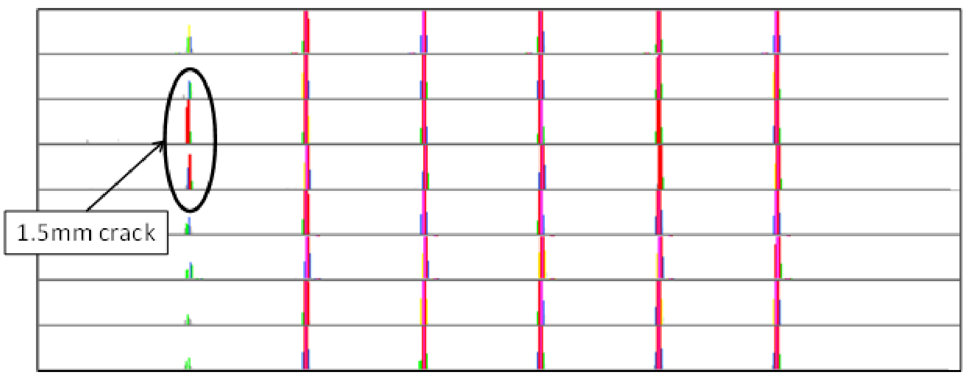

Figure 12: Signals from the cracks obtained from the Multi-Differential Sensor

Figure 12 shows the signals of the Multi-Differential sensors. The left-most line is the weld with an embedded crack-like defect. The signal amplitude and the phase (not visible here) allow the crack to be distinguished from the rest of the weld. The red lines farther to the right show the signals of tack-welds for the other defect joints. As the gap between different joints is similar to a crack like defect, the signal is visible as well.

Erosion Defects

Figure 13 shows the signals of the erosion type defects. As seen on the image all of these defects are detected. The data was obtained with the MEC™ sensor in absolute mode. Also visible on this image is the external notch. It is used to calibrate the sensors. As it is external, it is much more pronounced at lower frequencies.

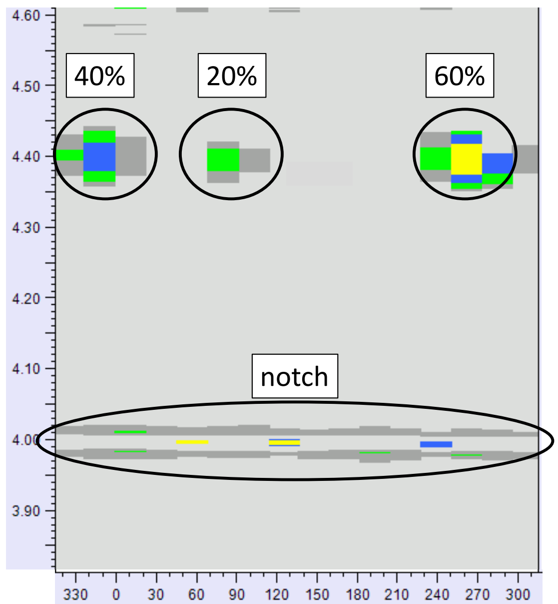

Figure 13: Erosion type defects (type B) in the top of the figure.

A proper defect sizing seems to be easily possible as the signals depend on the defect depth and the size of the color patch roughly represents the size of the erosion.

Internal Metal Loss

Figure 14 shows the results of the internal metal loss defects. The defects shown in this image are all hidden underneath the liner, i.e. there is no contact with the surface. The defects are grouped according to their diameter, with the 24 mm (1“) defects in the bottom, the 12 mm (½”) defects in the center and the 6 mm (¼”) defects on top. All of the defects are detected, including the 10% deep metal loss with 6 mm diameter. In terms of detection capabilities no further refinement seems required. The signals are obtained with the MEC™ sensors in differential mode.

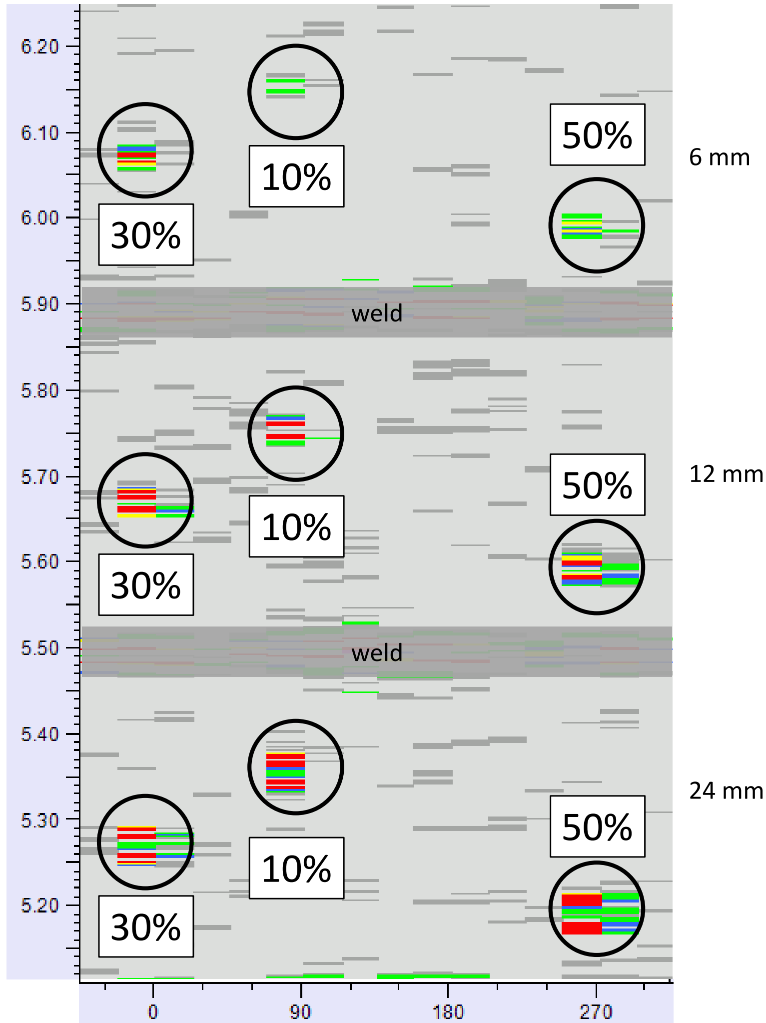

Figure 14: Signals of metal loss defects underneath the liner.

Figure 15 compares the defects under the liner (lower part of the figure) with the defect (D10) that is exposed to the inner surface (upper part of image). At lower frequencies both types of defects are visible. At higher frequencies the liner becomes opaque for the eddy currents and only the defect D10 with a 3 mm hole in the liner remains visible. The signal corresponds to the size of the metal loss. This is shown in the left of the figure. At low frequencies the signal can be decomposed into one part corresponding to the metal loss in the carbon steel and one part corresponding to the metal loss in the liner.

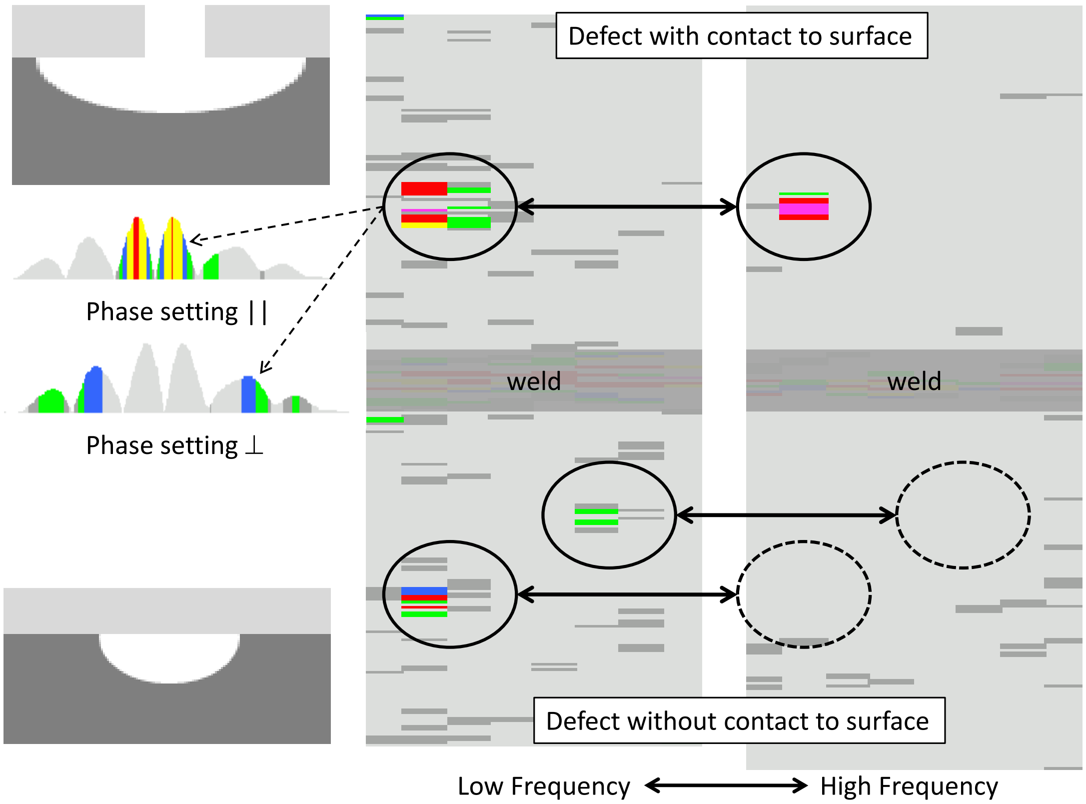

Figure 15: Comparison of internal metal loss defects at different frequencies (center to right). The defect with contact to the surface remains visible even at higher frequencies (top). The defect hidden under the liner disappears (bottom).

Conclusions

The Magnetic Eddy Current inspection technology allows finding and sizing defects in CRA lined pipelines. In particular this technology allows for inspection through the CRA into the ferritic steel to find crevice corrosion and external defects.

The success of the external small diameter defect detection even through an electric conductive layer (CRA clad) demonstrates the potential of applying the technique on non-metallic lined pipe and non-lined pipes for small feature detection and for heavier wall pipelines.

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[1] ILI in CRA-clad and lined pipes, Abdullahi Atto, NDT Global, PPIM Houston 12th to 13th Feb. 2014

[2] In-line Inspection of pipes using corrosion resistant alloys (CRA), M.Sc. Johannes Keuter, Rosen RTRC Lingen, PPSA Seminar Nov. 2014