# SHALLOW INTERNAL CORROSION SENSOR TECHNOLOGY FOR HEAVY PIPE WALL INSPECTION

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## Abstract

In-line corrosion inspection plays a key role in pipeline integrity assessment. Detection and monitoring of fast growing corrosion processes, such as Top of Line Corrosion (TLC) or pitting at the inner surface of heavy wall pipes is therefore inevitable for the save operation of off- and onshore pipelines.

In order to optimize the monitoring of Shallow Internal Corrosion (SIC), a new detection device has been developed on the basis of Eddy Current (EC) technology. The sophisticated SIC tool provides not only the determination of the corrosion status and growth rate, it also enables one to gain detailed information about the internal diameter and shape, such as ovality and dents. Shallow defects of even minor sizes are detected for assessing the degradation process resulting from internal corrosion.

Here, an introduction to the SIC inspection technology is presented.

## Introduction

Prevalent growth of corrosion constitutes a major risk for pipeline integrity and operation. For instance, Top of Line Corrosion (TLC) can occur in wet gas pipelines due to condensation. Growth rates were found to be up to several millimeters per year, when certain conditions are met, e.g. the excess of certain concentration levels of carbon dioxide and sulfur or organic acids [1,2]. Further examples of progressive deterioration processes are Microbially-Induced Corrosion (MIC) and pitting [3].

While onshore pipelines are predominantly deteriorated by third party damages and external corrosive processes, their offshore equivalents are primarily threatened – besides occasional anchor damages – by internal corrosion. In order to allow a specified maximum corrosion growth rate and, hence, a controlled reduction of the wall thickness during the lifespan of a pipeline, heavy wall pipes are commonly employed for offshore applications.

In view of the developments in design, construction and maintenance of heavy wall offshore pipelines, ROSEN has triggered the deployment of a new in-line inspection (ILI) technology. Based on an Eddy Current (EC) approach, a new sensor technology was developed, allowing a highly resolved and accurate image of a pipeline's inner surface. Besides providing detailed information about the internal diameter and shape, i.e., ovality and dents of the pipeline, Shallow Internal Corrosion (SIC) inspection results can be used not only for determining the corrosion status of the pipeline, but they primarily enable one to estimate the growth rate of a corrosion attack in the initiation phase.

The approach presented here gives a depth measurement of metal loss defects in terms of absolute figures, i.e., the wall thickness is not determined by the SIC sensor technology. It rather supplements relative wall loss measurements of Magnetic Flux Leakage (MFL) tools. SIC tool measurement results can substantially exceed MFL depth sizing of shallow internal corrosion. Otherwise, a SIC tool can support MFL defect identification or depth sizing with its higher spatial resolution, leading to an increased distinction of individual pits in dense clusters. Pits with diameters of at least 10 mm and minimum depths of 1.0 mm can be detected. Internal shallow defects with a maximum depth of 10 mm are sized with a high accuracy of +/- 0.5 mm. Hence, a good approximation of even marginal corrosion growth rates to monitor the degradation process is facilitated. The estimations can be subsequently used to predict failure pressures and life times in the context of limit state design guidelines [4].

**Fundamentals of shallow internal corrosion sensoring**

Following a well-proven high-resolution caliper tool design [5], the SIC sensor carriers are mounted on an ILI tool by spring-loaded arms for smooth guidance along the pipe's inner surface. The EC measurement method is essentially contactless. Mechanical displacements of the sensors in radial direction due to geometry changes of the line are additionally monitored by angle measurements of the individual suspension arms.

An ILI tool which combines both SIC and MFL technologies is shown in
Figure 1. The tool consists of a MFL front unit and a combination of a high-resolution geometry sensor with a SIC sensor on the second unit.

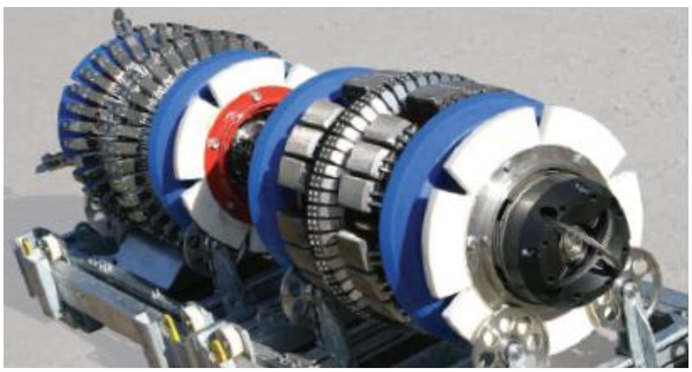

Figure 1: Combination of inspection technologies on a single 30" ILI tool. The front unit consist of a high-resolution MFL unit, the second unit is utilizing a combination of high-resolution geometry sensor with SIC probes.

The EC testing method is based on the approach of generating electrical currents in conductive materials. An alternating current with defined amplitude and frequency is applied to a coil system. The driving current generates an alternating primary magnetic field which causes ECs to flow in the surface of a nearby pipe wall by mutual inductance (see Figure 2). The currents in the pipe wall produce a secondary magnetic field which is opposite to the primary field inducing it. Defect damages, such as corrosion, lead to a change of the ECs flow direction. This change influences the mutual inductance, i.e., the resulting field of the superposed primary and induced secondary magnetic field is changed. This can be described by a variation in the electrical impedance of the coil, i.e., its ohmic resistance and inductive reactance. The impedance is usually measured across a bridge circuit which imbalance can be measured accurately. On the basis of this imbalance, material inhomogeneities can be detected and their properties determined by the evaluation of the amplitude and the phase shift between the input and output signals. Hence, by detection of eddy currents generated in the pipe wall via coil systems, a highly sensitive characterization of surface metal loss defects is possible.

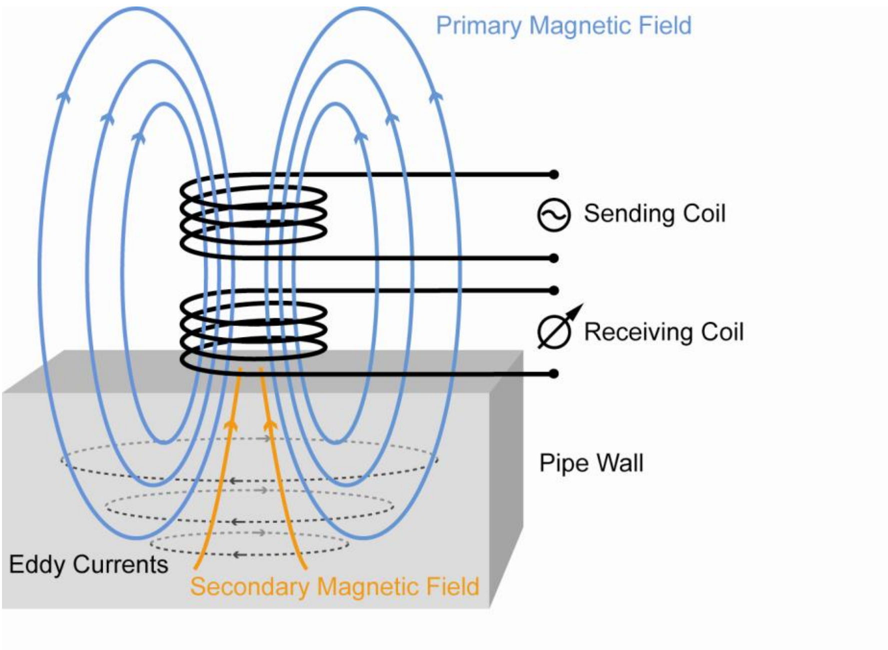


Figure 2: Schematic sketch of coil system for measuring metal loss.

Besides several material properties, e.g., conductivity, magnetic permeability and the presence of defects, the frequency of the input signal determines the so-called skin depth of ECs as well. The skin depth is a measure of the distance which an alternating current can penetrate beneath the surface of a conductive material, i.e., the pipe wall. For achieving an optimum performance of the new SIC sensor technology, settings were chosen that are adequate within certain capabilities for spatial dimension sizing. For frequencies being suitable for in-line inspection, the skin depth of ECs in carbon steel lines is well below 1 mm. Hence, the EC approach can be considered as a surface sensitive method. This is in stark contrast to MFL measurements where signals are mainly affected by volume changes of metal loss.

**Monitoring shallow internal corrosion**

The strongest effect on mutual inductance results from distance variations between sensing coils and pipe wall. This separation is also referred to as lift-off. Related signals show a saturation behavior for increasing distance between coil and wall. Therefore, a maximum lift-off value exist within certain accuracy limits. Figure 3 shows a maximum value of 10 mm depth for large surface metal loss defects. It illustrates the maximum sizable depth of the SIC technology and, thus, the threshold for internal metal loss defect sizing regimes between SIC and MFL. In contrast to SIC, MFL is best suited for deeper and – more generally spoken – larger volume metal loss defects. However, MFL could also be used in parts of the SIC sizing regime (blue area), but then with minor performance in joints with high wall thickness if compared to SIC. Results from SIC measurements can likewise also assist MFL feature depth sizing algorithms in the MFL regime (green area) by maximum signal indications and providing increased resolution of feature width sizing. Both measurement approaches complement one another and show synergetic effects. They can be used to increase the overall sizing performance for corrosion growth monitoring.

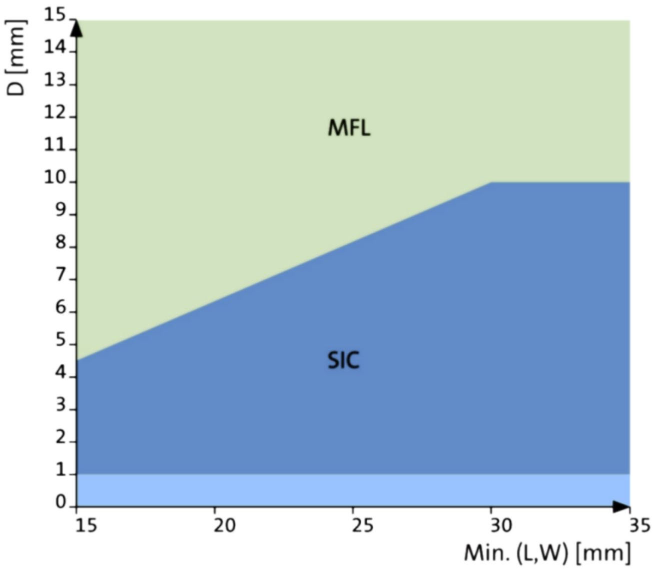


Figure 3: Optimal sizing regimes of the MFL and SIC inspection methods for internal metal loss defects depicted for a 15 mm wall thickness. The green and blue areas indicate the favored sizing regimes of these two techniques, respectively. The light blue area in the figure illustrates that for a feature depth less than 1 mm the Probability of Detection (POD) with metal loss characterization is smaller than 90%. (L = length, W = width, D = depth of feature.)

A comparison of SIC and MFL signals is given in Figure 4. Different excerpts of c-scans are presented to show the difference in signal characteristics for bore holes in a pull test 16" line (see caption for details on defect setups). A closer inspection of the mid lane (no. 2) results in the finding of a significantly increased lateral resolution of SIC related data. A pair of bore holes with an edge-to-edge separation of 20 mm can be separated by SIC clearly, but not by MFL. The inset data shows a raw SIC data trace, i.e., before conversion to a lift-off scale, with high signal-to-noise ratio, which demonstrates an intrinsic high POD even for pinhole corrosion.

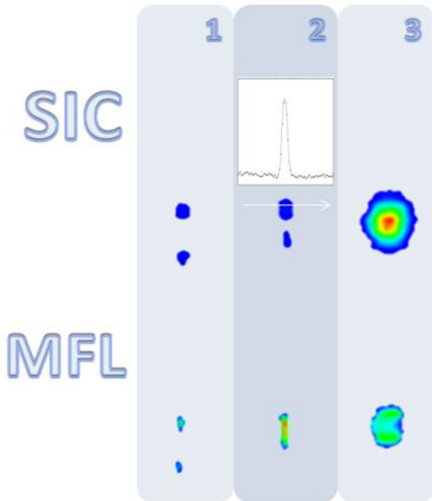


Figure 4: Defect patterns are shown twice, as SIC pseudo-lift-off (top) and MFL field strength (bottom) data, respectively. The vertical lanes differentiate the test features, which were made in a 16" joint with 12.6 mm wall thickness: (lane no. 1) 2 bore holes with 10 mm diameter each and edge-to-edge separation of 40 mm in circumferential direction of the pipe, (no. 2) like the previous lane, but bores with edge-to-edge separation of 20 mm, and (no. 3) a bore hole with a diameter of 35 mm. The inset shows a SIC raw signal trace, i.e. before conversion to pseudo-lift-off scale, whereas its positions in the c-scan are indicated by the white arrow.

The example as shown in Figure 5 is a further performance demonstration of the new SIC sensor technology. The left-hand side gives a photo showing a pitting cluster in a steel plate. It reveals characteristics being similar to that of TLC or bacterial corrosion. The right-hand part shows corresponding data with a step size of 2 mm in both directions of the surface. The measurement was made with a SIC sensor in a laboratory setup. A specific pseudo-lift-off conversion was used that showed a very good depth sizing performance even for such pitting defects with unfavorable surface-to-depth ratios (i.e. pit diameter is only a factor of 2 to 3 larger than the maximum depth).

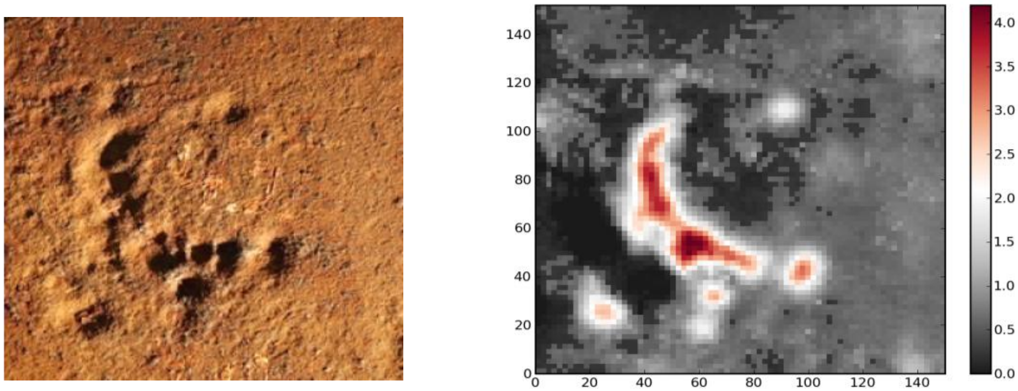


Figure 5: (*left*) Pitting corrosion in a steel plate. (*right*) The corresponding data made with a SIC sensor in a laboratory setup with sample spacing of 2 mm in both directions and a specific pseudo-lift-off scaling (all values in mm).

For successful in-line inspection, proper signal conversion requires hardware with exceptionally stable readings within the range of operating conditions. A tight coil spacing in the circumferential direction ensures a high repeatability of the spatial dimension measurements.

An example of TLC is given in

Figure 6. Here, a test line has been used to investigate the performance of a tool equipped with SIC sensors (left panel) and compare it with results obtained with automatic UT (right panel). The dimension of both excerpts is 40 cm in both directions, respectively. The maximum metals loss depth measured is approximately 2 mm. At a glance, the corrosion patterns as given in both excerpts can clearly be associated.

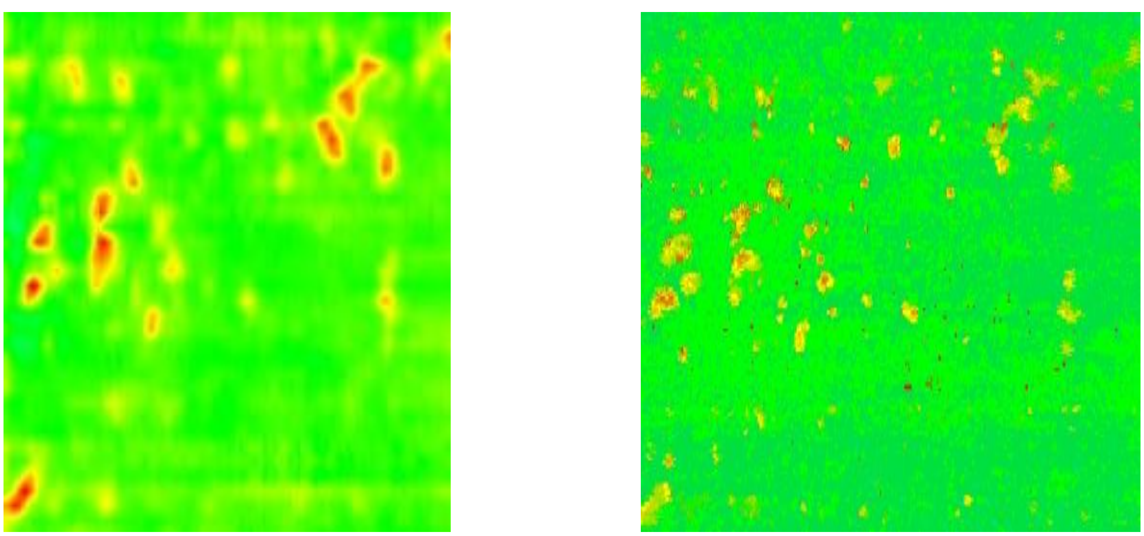

Figure 6: Top of line corrosion in a test pipeline. The left panel shows inspection results obtained with a SIC tool, the right figure represents data derived from an automatic UT measurement. Corrosion patterns in both excerpts can easily be correlated.

## Conclusions

The new sensor technology presented here is designed to facilitate and optimize the process of monitoring shallow internal corrosion. There are virtually no restrictions to ILI tools that can be equipped with such a technology. Therefore, they can be used even under exceptionally challenging conditions.

In view of a high lateral resolution of defect surface measurements, not only individual pits in dense clusters can be detected and accurately distinguished, but it also enables one to size even marginal corrosion features with great accuracy. Hence, the SIC technology provides invaluable information on asset degradation. ILI tools equipped with SIC sensor technology pushes corrosion growth monitoring to new quality standards.

## References

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