Detecting metal loss and pipeline wall thinning with a combination of Ultrasonic Testing (UT) and Magnetic Flux Leakage (MFL)

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Abstract
In-line inspections with Ultrasonic Testing (UT) and Magnetic Flux Leakage (MFL) have become standard for pipeline integrity management programs worldwide. UT allows direct and highly accurate measurements of two-dimensional features, notably pipeline wall thickness. In contrast, MFL provides a versatile and dependable method for determining the geometry of metal loss in pipelines. ROSEN has developed a system that combines the two technologies in the single inspection tool RoCorr·MFL/UT. While the UT unit of this tool accurately scans general wall thinning and uniformly corroded areas, the MFL component supplies detailed information on smaller anomalies such as pitting corrosion. This paper shows that since the two technologies ideally complement each other, their combination constitutes an important step forward on account of its great benefits for asset integrity programs and operational cost management.

Introduction
Used as standard inspection methods in pipeline management programs all over the world, both Ultrasonic Testing (UT) and Magnetic Flux Leakage (MFL) are extremely powerful ILI technologies. Whereas UT identifies two-dimensional features such as wall thickness as well as large uniformly corroded areas with high accuracy, MFL provides a flexible and reliable method for determining the geometry of metal loss in pipelines. Used on its own, however, UT often fails to reveal small corrosion pits and internal defects covered by wax and other deposits. Similarly, MFL has limits with regard to the identification of evenly corroded segments as well as two-dimensional mid-wall discontinuities, notably laminations. On the basis of technological innovations developed in-house, notably a “plug and play” system for combining different types of inspection tools, standardized data processing, and miniaturized sensors, ROSEN has succeeded in combining both technologies in a single inspection tool, thereby greatly increasing the accuracy, reliability and efficiency of UT and MFL inspections. Compensating for the relative weaknesses of each individual technology, the new Combo tool RoCorr·MFL/UT not only provides highly reliable information on a number of different aspects such as metal loss as well as geometry and pipeline wall features, but it delivers all this data on the strength of only one inspection run (see Figure 1).
General points on the advantages of combined technologies for asset integrity and operational risk management

One important aspect of integrity management programs, which are typically used as a basis for operating pipeline systems, is the selection of an adequate in-line inspection method. In general, this choice is based on the prospective threats determined by means of pre-inspection risk analysis of the pipeline. Representative examples of such threats include Microbiological Corrosion (MIC) and Top of Line Corrosion (TOL) (see Figures 2 a and b). Once the corrosion levels in the pipeline have been established, another important task of the integrity management program is to find out whether the corrosion detected is dormant or active. In the latter case, corrosion growth analysis is used to ascertain the growth rates for these anomalies.

Figure 2 a: Microbiological corrosion (MIC) poses a significant threat to pipeline integrity.

Figure 2 b: Top-of-line (TOL) corrosion too can result in serious damage to pipeline systems.

To ensure asset integrity it is imperative that increases in corrosion depth are reliably identified, even very slow changes occurring over many years. Corrosion growth analysis therefore depends on highly accurate inspection results. As will be explained in detail below, the combination of two independent inspection methods results in significantly higher accuracy levels. The simultaneous use of UT and MFL therefore makes an invaluable contribution to corrosion growth analysis as a basis for successful integrity management. In addition, combined in-line inspection technologies also benefit integrity management in more general ways: their wider application range not only reduces the need for future threat analysis but also minimizes the risk of choosing the wrong inspection technology for a given pipeline situation.
Over and above the direct benefits combined inspection technologies have for asset integrity management, they also reduce operational risk. Inspections often involve great expense in terms of time and money. While pipelines require a reduction in flow or pressure, the inspection tool must be operated in a clean condensate in crude oil pipelines. In other cases, expensive cleaning measures are necessary before the inspection can take place. In all these situations, the repeated launching, receiving and tool tracking procedures resulting from the separate use of different technologies not only lead to additional inspection risks, but also to higher operating costs. Applying different types of inspection systems in a single run, combined technology solutions significantly reduce these risks and costs.

**Combining UT and MFL for enhanced detection accuracy, reliability and efficiency**

Before discussing the specific benefits resulting from the combination of UT and MFL, a brief explanation of the measurement principle, strengths and weaknesses of each inspection method is required. Taking into account relevant factors such as the velocity of ultrasound in the coupling fluid (e.g. oil or water) and in the pipe wall, UT metal loss and wall thickness inspections measure the time of flight of ultrasonic waves reflected from the internal and external surfaces of the pipe wall (see Figure 3). The strength of the UT method is direct measurement of two-dimensional features, notably pipe wall thickness. The weakness of UT inspections is that they cannot, as a general rule, detect pitting defects smaller than 10 – 20 mm. In addition, a well-known disadvantage of UT measurements is missing information due to debris which can divert the ultrasonic beam. This means that small defects are difficult to identify thus lowering the overall probability of detection, if this system is used on its own.

![Figure 3: The UT unit quantifies the time of flight of ultrasonic signals reflected form the internal and external surfaces of the pipe wall. Since the velocity at which ultrasound travels within the coupling fluid (e.g. oil or gas) and the pipe wall is known, the time-of-flight data can be used to measure wall thickness.](image)

The MFL inspection method is based on a different measurement principle. A magnetic flux is created which “leaks” out of the pipeline, if internal or external metal loss is present. Since this leakage is recorded by hall-effect sensors, it is possible accurately to infer the location of defects (see Figures 4 a and b). One special feature of this method is that registered MFL patterns appear larger than the anomaly itself. In consequence, MFL is especially sensitive even to very small pitting defects; even under extremely poor conditions, a magnetic response is still obtained from such anomalies. This strength of MFL technology is at the same time the weakness of the UT...
inspection method which cannot, as seen above, detect very small flaws. Conversely, although the thickness of the pipe wall can not only be determined on the basis of UT but also MFL data, measurements of two-dimensional features by the latter method are less reliable, since they are calculated indirectly by means of a comparison of the MFL readings from various calibration joints.

Figure 4 a: Flux line distribution in a pipeline without any flaws

Figure 4 b: Flux line distribution in a pipeline with an external defect

Figures 4 a and b: In a pipeline without any defects, the propagation of the magnetic flux created by the MFL tool is undisturbed (Figure 4 a). In contrast, both internal and external metal loss results in the flux “leaking” out of the pipeline (Figure 4 b). Character, amplitude and various other measurements of the disturbance are used to determine the depth, length and width of the recorded metal loss.

At a more general level, a universal mathematical principle states that the confidence level of measurement results can be improved by combining two independent measurement systems. This principle is expressed in the following formula which uses UT and MFL as examples of the two independent measurement systems:

$$C_{COMBO} = 1 - (1 - C_{MFL})(1 - C_{UT})$$

In this mathematical expression, C is the confidence level of a Gaussian distribution sample. Since the accuracy of a measurement is directly linked to the confidence level in case of a known distribution, an improvement in accuracy follows which can also be mathematically expressed. For example, assuming an accuracy of 0.1*t, where t is the wall thickness, and a confidence level of 90 % for UT and 80 % for MFL measurement of defect depth, the combination of the two methods results in the following expression:

$$+/- 0.04*t$$  90 % confidence

This high confidence and accuracy level could under no circumstances be achieved with one inspection technology alone, since it is a direct outcome of the combination of the two independent inspection methods MFL and UT.

It follows from the universal mathematical principle, then, that the combination of two different inspection systems per se leads to higher confidence and accuracy. In addition, it is now possible to present – on the basis of the above explanations of the measurement principles employed by the two inspection methods UT and MFL – specific technological reasons why their combination is particularly effective. The most basic point to note in this context is that either one of the two measurement methods is highly sensitive precisely to the type of anomaly that its counterpart cannot detect accurately. Moreover, the combination of precise knowledge of the exact wall thickness and well-known magnetization levels substantially reduces the risk of systematic errors when anomaly populations are sized. The UT/MFL combination therefore significantly diminishes
the potential need for extensive dig-up programs. Finally, the technological combination makes possible mutual error elimination. Thus UT data can be used for correction of the MFL model and vice versa.

Overall, the simultaneous application of MFL and UT overcomes limitations with regard to small pitting anomalies (weakness of the UT method) and the precise measurement of two-dimensional features (weakness of the MFL method). In combination, therefore, MFL and UT provide high accuracy in length, depth and width measurements for exact defect shapes and precise information on general wall thinning. The obtained defect shapes allow more detailed profile determination supporting assessment codes such as RSTRENG. At the same time, the improved defect classification resulting from the UT/ MFL combination translates into fewer false alarms. Inspection tools combining both methods furthermore show excellent detection performance for numerous metal loss flaws (e.g. pitting, axial grooving, circumferential grooving), mid-wall features (e.g. lamination, inclusions, blisters), weld features (e.g. girth welds, longitudinal welds, spiral welds), geometry features (e.g. dents, ovalities, misalignments), and other features (e.g. valves, fittings, bends).

Conclusion
Integrating the two non-destructive testing methods Magnetic Flux Leakage and Ultrasonic Testing, the new RoCorr·MFL/UT tool developed by ROSEN enables detection of common defects such as corrosion pitting and irregular general corrosion while also accurately sizing large uniformly corroded areas and laminations. Capable of inspecting pipelines between 6” and 40” with a maximum length of 255 km, ROSEN's RoCorr·MFL/UT measures pipeline wall thickness to an accuracy of ±0.2 mm and passes through a minimum bend radius of 1.5D. As shown, the combined use of UT and MFL leads to a significant increase in the accuracy, reliability and efficiency of inspections, both because the two methods ideally complement each other and because all data is gathered on the strength of a single run. While the accuracy and reliability of the collected data makes an invaluable contribution to asset integrity management in that it can be used as a basis for more advanced fracture mechanics assessment of pipeline defects, the efficiency of a single run considerably reduces operational risk and cost.