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Practical Uncertainty Propagation in Corrosion Growth Estimation from Successive In-Line Inspections

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ABSTRACT

The oil and gas pipeline industry has utilized in-line inspection techniques to assess pipeline integrity for more than 50 years. Successive inspections of the same pipeline can be compared and evaluated to estimate corrosion growth. This paper demonstrates the capabilities and significant benefits of corrosion growth analysis and highlights an enhanced quantitative approach to direct signal comparisons. The propagation of measurement uncertainty into the corrosion growth estimate is considered, including discussing how the overall uncertainty varies depending on whether the same or different in-line inspection tools are used in the successive inspections. Simple statistical techniques that can be applied in actual pipeline integrity practice are emphasized.

Keywords: corrosion growth analysis, in-line inspection, uncertainty

INTRODUCTION

Magnetic flux leakage (MFL) has been used extensively for assessing the integrity of pipelines affected by metal loss defects caused by corrosion. In addition to a single point-in-time pipeline assessment, multiple MFL inspections of the same pipeline can be compared and assessed for a greater understanding of a pipeline's integrity. The basic processes and technologies for comparing two in-line inspection (ILI) runs to estimate corrosion growth were introduced into the pipeline industry more than 20 years ago [1].

Feature alignment is performed to establish the correspondence of reported results between two or more ILI runs. Using the same ILI technology platform to align the data sets for run comparison and corrosion

growth is optimal, but different technologies can also be aligned and compared. Once the data sets are aligned, a comparison of prior and current metal loss features is performed to estimate corrosion growth.

Experience shows that the uncertainty associated with comparing subsequent MFL inspections is generally smaller than a simple analysis of the accuracy specifications between inspections suggests. It has long been understood that uncertainty in corrosion growth analyses can be significantly reduced by using the same MFL system and sizing model [2]. Additional improvements to corrosion growth estimates can be made with access to the full MFL signal information. This experience prompts a closer examination of the uncertainties associated with MFL depth. Two sources of uncertainty in MFL depth measurements will be examined: ILI model uncertainty and ILI repeatability uncertainty. With a better understanding of uncertainties in hand, statistical techniques can then be applied to conservatively interpret the resulting estimated corrosion growth rates for practical use in projecting pipeline integrity out into the future.

METHODS

Assume two ILIs of the same pipeline exist spaced apart by some time interval T , which is known with negligible uncertainty. Assume that the corrosion growth rate c on the pipeline can be estimated by the simple relationship

$$c = \frac{d_2 - d_1}{T} \quad (1)$$

where d_1 and d_2 represent the metal loss depth estimates obtained from the first and second ILIs, respectively. An in-depth discussion of corrosion growth as a random process can be had elsewhere [3] and is not pursued further. Instead, (1) is selected as a simple, practical model for estimating the progression of corrosion that has been applied many times in the industry. It serves as a simple vehicle for studying how ILI uncertainties propagate through the growth rate analysis.

Rather than examine the uncertainty in the full corrosion growth rate, without loss of generality it is simpler to consider just the estimated depth difference Δ as

$$\Delta = d_2 - d_1 \quad (2)$$

and then recognize that growth rate uncertainty is easily obtained by dividing by T at some point later. Dropping the T here simplifies the discussion and focuses attention on the primary terms that contribute meaningful uncertainty. The depth estimates d_1 and d_2 both contain uncertainties associated with the ILI technology used to obtain them. The prefix δ is used to indicate the uncertainty in a variable. The uncertainties δd_1 and δd_2 propagate through the computation to create uncertainty in the estimated depth difference Δ . If d_1 and d_2 are independent measurements then the uncertainties in the depth measurements combine in a root-sum-of-squares fashion [4] to become

$$\delta\Delta = \sqrt{(\delta d_2)^2 + (\delta d_1)^2} \quad (3)$$

Considering a typical MFL depth uncertainty of $\pm 10\%$ of wall thickness (WT) at 80% certainty, this would imply a typical depth difference uncertainty on the order of $\pm 14.1\%$ of WT at 80% certainty when comparing two MFL ILIs, even for anomalies that are not changing depth.

Experience shows that this much scatter in depth difference is rarely observed in practice. When using the same ILI system with the same sizing model, the observed scatter is significantly smaller than this. What is happening to reduce this scatter? To address this question, the contributions to MFL depth uncertainty will be examined in more detail. The sources of uncertainty studied in MFL inspection represent similar sources of uncertainty in other ILI technologies; consequently, the discussion will

generalize beyond just MFL. The uncertainty in MFL depth measurement will be decomposed into two sources: ILI model uncertainty and ILI repeatability uncertainty.

ILI Model Uncertainty

Figure 1 shows an example cluster of metal loss anomalies and the associated *idealized* axial MFL signature. In this context, the notion of *idealized* MFL signature represents the perfect, noise-free flux leakage surface observed from an *idealized* implementation of the MFL system in question. The idealized MFL surface is never observable since real MFL systems always demonstrate some imperfection in recording the flux leakage surface.

In MFL inspection, signals like those on the right of Figure 1 (in this instance, the axial component of the flux leakage field from an axial magnetization) are observed and analyzed to make some estimate of the size of the metal loss geometry that produced the signals. Even if the idealized MFL surface was perfectly observed, there would still be uncertainty associated with the models that estimate the geometry on the left of Figure 1 (in this instance, depth as indicated by a laser scanner), since this type of inversion problem on magnetic field data does not yield a unique solution [5]. The uncertainty associated with the model employed to invert the idealized MFL signal into an estimate of metal loss size is called *ILI model uncertainty*.

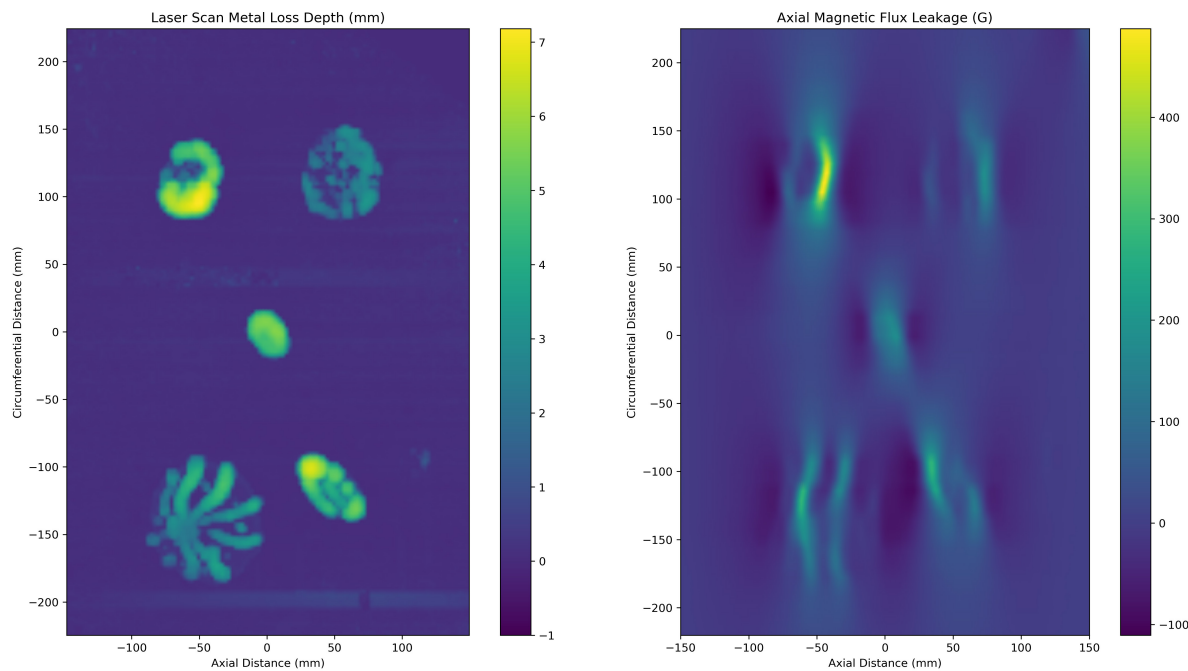


Figure 1. The metal loss geometry represented in the laser scan data on the left produces the ideal axial MFL response on the right.

ILI Repeatability Uncertainty

The idealized axial MFL surface is shown again on the left in Figure 2. Real MFL systems are not capable of observing the idealized surface and instead observe a noisy version of it at each attempt. Repeated inspections on the same anomaly will produce slightly different real MFL observations at each attempt, as depicted on the right of Figure 2. These deviations from the idealized response in practice are related to finite-sample pitch in both axial and circumferential directions, physical dynamics of the tool and sensor heads as they traverse the pipeline, electrical and quantization noise associated with acquiring the sensor signals and other similar sources. The uncertainty associated with the inability of a real MFL system to return the idealized MFL surface is called *ILI repeatability uncertainty*.