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## MANUAL UT VS PERMANENTLY INSTALLED SENSORS

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### ABSTRACT

Ultrasonic NDE and inspection techniques are often strongly influenced by procedures and human factors as well as the underlying physics of the measurement technique. Automation of some of the acquisition tasks potentially eliminates some sources of error. The NDE group at Imperial College London has developed permanently installed ultrasonic thickness monitoring tools which allow frequent acquisition as well as automatic evaluation of ultrasonic wall thickness estimates. Several thousand sensors have been deployed in field and some of the outcomes from site data will be presented. The factors that influence the automated system's performance will be discussed in this paper with a view to giving an indication of the different aspects that are important when trying to evaluate thickness measurements as a function of time. The automated thickness measurements are then compared to measurements that are collected with manually collected measurements using the conventional inspection approach.

**KEYWORDS :** *Ultrasonics, Corrosion monitoring, SH waves, High temperature, SHM.*

### INTRODUCTION

One of the main inspection techniques for corrosion damage is by means of manual ultrasonic thickness gauging. Large process plants usually have many thousand or even several million thickness measurement locations (TMLs) at which regular inspections are carried out. The requirement for these inspections is either imposed by external regulation or self imposed by the operator to ensure more effective operation of the plant. There have been several studies on the measurement error associated with manual thickness measurements (e.g. [1] or [2]) and these have shown that there is substantial spread in thickness data that is collected from the same component because of the many factors that influence the measurement: Equipment Setup, Probe coupling, Data reporting, etc.. In the work by van Roodselaar et al. [2] a graph showing measured vs actual thickness on real corroded samples measured in a test environment was shown and an illustration of this graph is reproduced in figure 1.

There are many causes for the measurement errors and one usually refers to the three P's: People, Procedure and Probe. Two of these error sources are associated with the operator and the procedure in which the operator applies the test. It is attractive to try to eliminate errors caused by Operators and non-adherence to the procedure by automating measurements. Automation either can be achieved by c-scans with automated scanning equipment or by permanently installing ultrasonic probes at the TML, which stay in place and take measurements at regular intervals.

The author has been involved in the development of a permanently installable thickness gauge and many thousands of these sensors have been installed in industrial plants worldwide [5]. This paper will discuss and try to quantify some of the advantages of permanently installed sensors as compared to manual data acquisition. First some literature sources of wall thickness measurement

capabilities will be recalled. Then a model to quantify performance of thickness change and slope change will be presented and both methods will be compared. Finally, pitfalls and assumptions will be pointed out and conclusions drawn.

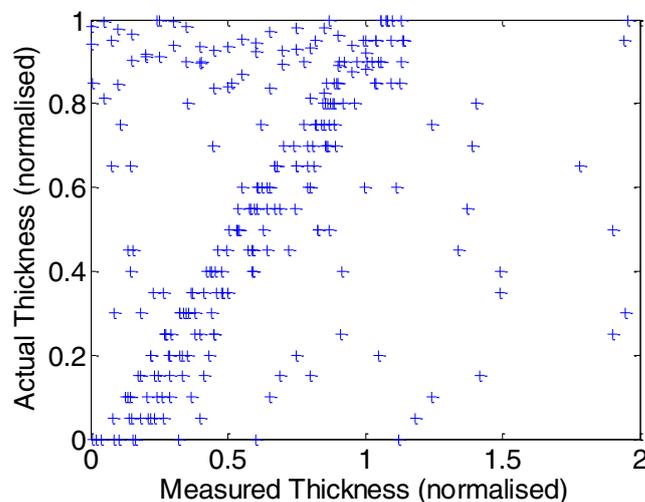


Figure 1: Illustration of measurement errors associated with manual ultrasonic thickness measurements on corroded steel samples (retired from plant). Sketched after data presented by van Roodselar et al. [2]

## 1 BACKGROUND

The purpose of inspections can be twofold. The main reason for wall thickness measurements is to check structural integrity, i.e. a thickness is measured and it is checked that it is above the minimum safe component thickness. Once thickness data is available a second very important analysis step can be carried out and this is to predict the rate of degradation and the component retirement time. This latter analysis is also an input into the determination of when the next inspection needs to be carried out or if components will survive until the next planned outage (unscheduled outages are very costly). In this paper we will try to compare how manual ultrasonic thickness measurements and measurements from permanently installed sensors perform in both these tasks.

In order to quantitatively evaluate the performance of the different measurement techniques a framework for comparison is required. The method chosen here is similar to the concept of probability of detection (POD) that is commonly employed in the field of non-destructive evaluation (NDE). However, because we are not detecting a defect but a change in thickness or a change in thickness trend the calculated quantity will be called the PDRC, the probability of detecting a real change given that a change has been detected.

To calculate the PDRC for wall thicknesses, it is assumed that an estimate of the mean of the initial wall thickness is known as well as the standard deviation of the measurement technique that is used to evaluate the wall thickness (it is assumed that measurements have a Gaussian distribution about the mean), it is also assumed that a second wall thickness measurement is available and that this measurement also has a mean value and the same standard deviation. Now, the detection of a change has to be defined and this is defined as when a thickness reduction of two standard deviations or more from the original value is measured. Any estimate for which change is detected is part of a new population of thickness estimates with new mean but the same standard deviation (std). It is therefore possible to calculate the PDRC by considering the overlap of the different areas

of the probability density functions (pdfs) of the original thickness population and the population of thickness for which a change has occurred. In equations this can be expressed as:

$$PDRC = \frac{PN}{PR + PN} \tag{1}$$

Where PN is the area underneath the pdf curve of the new thickness distribution below the 2std threshold and where PR is the area underneath the pdf curve of the original thickness distribution below the 2std threshold. See Figure 2 for a graphical illustration.

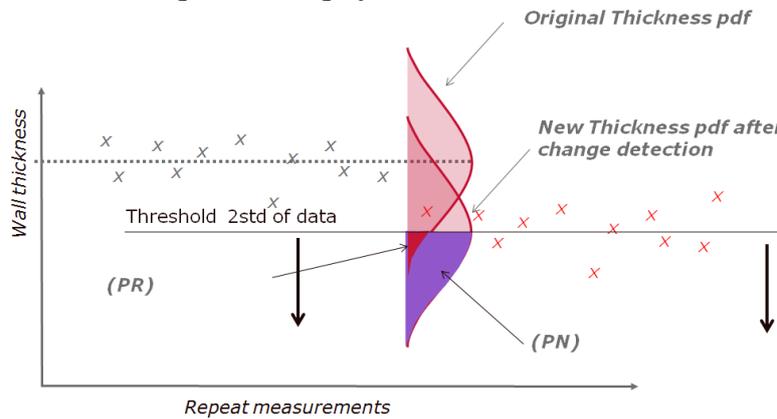


Figure 2: Illustration of the concept of PDRC determination for repeatedly sampled wall thickness data.

The same technique can be applied to the detection of a slope (trend) in the wall thickness measurements. For this, one first needs to estimate the pdf of the wall thickness slopes that randomly occur due to the spread in measurement data. This can be readily obtained from statistics handbooks see e.g. Bulmer [3]:

$$\sigma_{slope}^2 = \frac{\sigma_{meas}^2}{\sum_{i=1}^n (x_i - \bar{x})^2} \tag{2}$$

Where  $\sigma_{slope}$  is the standard deviation of the slopes that are determined from  $n$  measurements of standard deviation  $\sigma_{meas}$  and sampled at times  $x_i$  with mean value  $\bar{x}$ .

Using equation (2) the pdf of a randomly occurring slope can be determined for a measurement technique of given  $\sigma$ . One can then determine a 2 std threshold below which a change in slope will be detected. Following the same reasoning as for wall thickness change detection and using equation (1) one can then determine the PDRC of detecting a slope. This is illustrated in Figure 3.

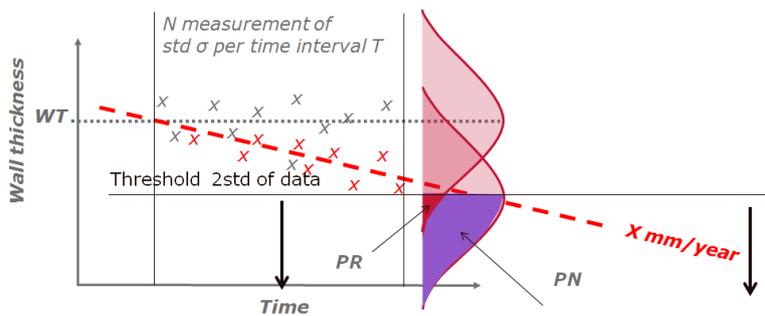


Figure 3: Illustration of the concept of PDRC determination for slopes of wall thickness data.

## 2 FIELD DATA AND CHANGE DETECTION

The previous section has introduced a change detection technique. In order to get some useable results out of this technique some realistic data needs to be fed into it. For PDRC of wall thickness changes the only information that is required is the standard deviation of the measurement technique. For the slope detection PDRC one also needs to specify  $n$ , number of measurements that were taken, and  $T$  the period over which the measurements were taken (it is assumed that they are taken at regular and equal time intervals). The main data input that is required is an estimate of the standard deviation of measurements that are collected in the field.

### 2.1 Manual Ultrasonic Thickness Tests

The literature was searched for data on manual ultrasonic thickness gauging. Data is scarce however three main references were found. Yi. et al [1], van Roodselar et al. [2] and Wilson et al. [4]. They report different values for the repeatability of manual ultrasonic thickness measurements on the same components (usually ex service components, but conditions varying from field to laboratory). The estimates of the measurement standard deviation (std) range from ~1mm (Wilson et al.) to ~0.25mm (Yi et al.).

Using these std values the PDRC for detection of a change in wall thickness was estimated and this is shown in figure 4. Also marked on the graph are the 90% PDRC values at 95% confidence, which are 0.8mm and 3mm for the stds in question.

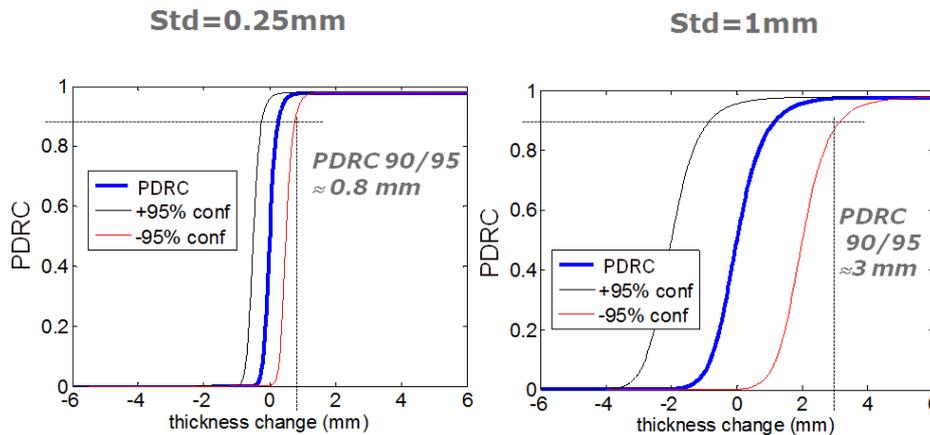


Figure 4: Calculated PDRC for wall thickness change detection and 95% confidence intervals for wall thickness measurement standard deviations of 0.25mm (left) and 1mm (right) as would be expected for manual ultrasonic thickness gauging according to the data reported in the literature [1], [2] and [4].

When fixing a time interval and the number of measurements taken over that time interval one can also extract the PDRC for detecting a change in slope, i.e. a wall loss rate or corrosion rate. The time period of interest was chosen to be 1 year and the number of measurements were chosen to be  $n=10$  (these seem like practically feasible values). Figures 5 shows the PDRC values calculated for both the manual std values reported in the literature.

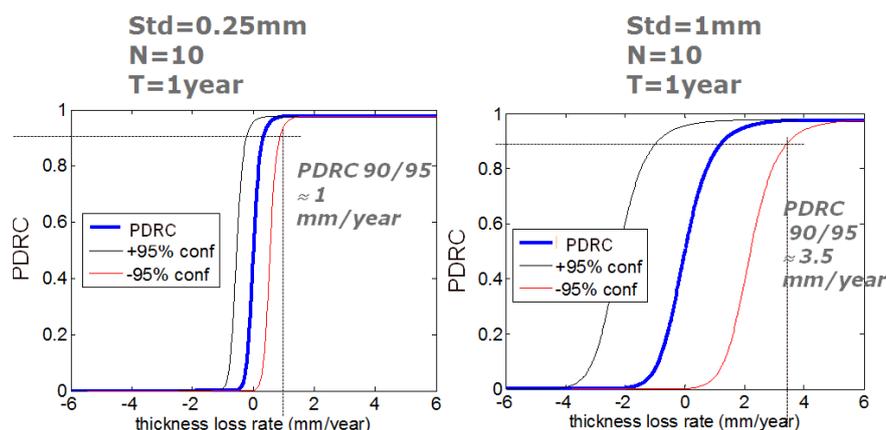


Figure 5: Calculated PDRC for wall thickness slope change detection and 95% confidence intervals for wall thickness measurement standard deviations of 0.25mm (left) and 1mm (right) as would be expected for manual ultrasonic thickness gauging according to the data reported in the literature [1], [2] and [4].

## 2.2 Results for permanently installed ultrasonic thickness gauges

Permanently installed thickness gauges suffer from less data variation because of automation of the acquisition procedure and elimination of coupling variability as well as other operator dependent factors. To gain an idea of the capabilities of a permanently installed thickness measurement repeatability two data sets that were acquired in the field with permanently installed sensors (similar to those described by [5]) were analysed.

The thickness data for two sensors is shown in figure 6, and it can be seen that the variability (std) for the first sensor is about 0.05mm over the period of 3 years and no thickness loss is evident. The second sensor shows more dramatic thickness loss, which is temporarily halted for 6 months. The standard deviation of the measurements in the period where the thickness is constant was determined to be 0.018mm over the period of 6 months. Although both of these sensors are nominally the same, they are mounted in a different environment where different levels of noise (such as RF signals and environmental condition variations such as temperature swings) can produce different levels of measurement spread. Another reason for measurement spread is the corrosion process itself, which produces rough surfaces and the level of roughness introduces spread in measured thickness data [6].

Data from 2 field installations

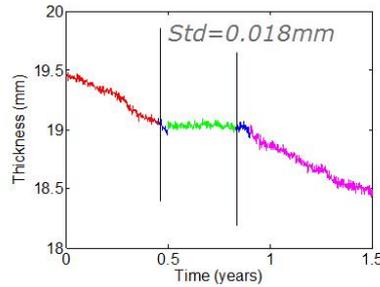
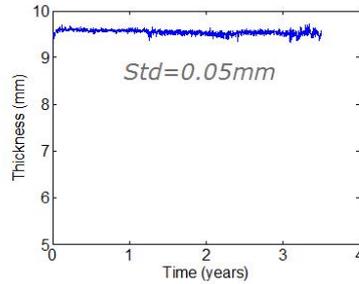


Figure 6: Picture of two permanently installed sensors (Permasense Ltd) and thickness history as recorded in the field.

Using these std values one can again calculate a PDRC for detecting wall thickness change with the permanently installed system and these are shown for measurements with variability equal to the two std values that were observed in the field. Figure 7 shows the result.

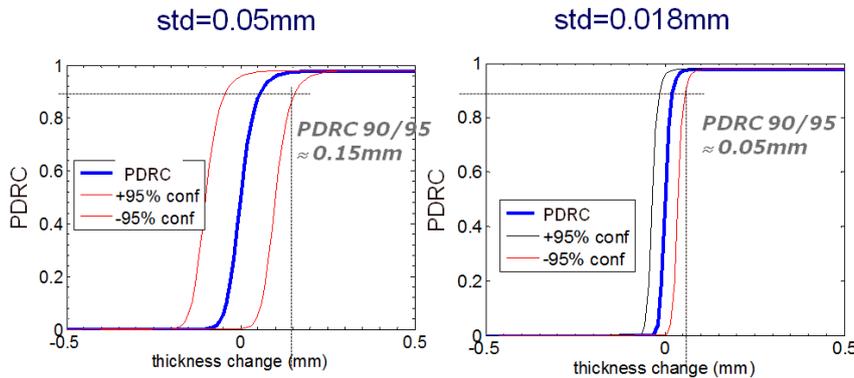


Figure 7: Calculated PDRC for wall thickness change detection and 95% confidence intervals for wall thickness measurement standard deviations of 0.05mm (left) and 0.018mm (right) as would be expected for permanently installed ultrasonic thickness gauges.

Furthermore, one can also deduce the PDRC for detecting changes in wall thickness slope using this method. Permanently installed sensors and automated acquisition make it possible to take many measurements at relatively short intervals.  $N=100$  or several 1000 measurements over the period of 1 year or months are easily possible with these systems, which would be uneconomical with manual acquisition. The PDRC for detecting a change in wall thickness slope (loss rate) is summarised in figure 8. The figure also shows the effect that changing the number of measurements ( $n$ ) and the total measurement period ( $T$ ) has on the PDRC.

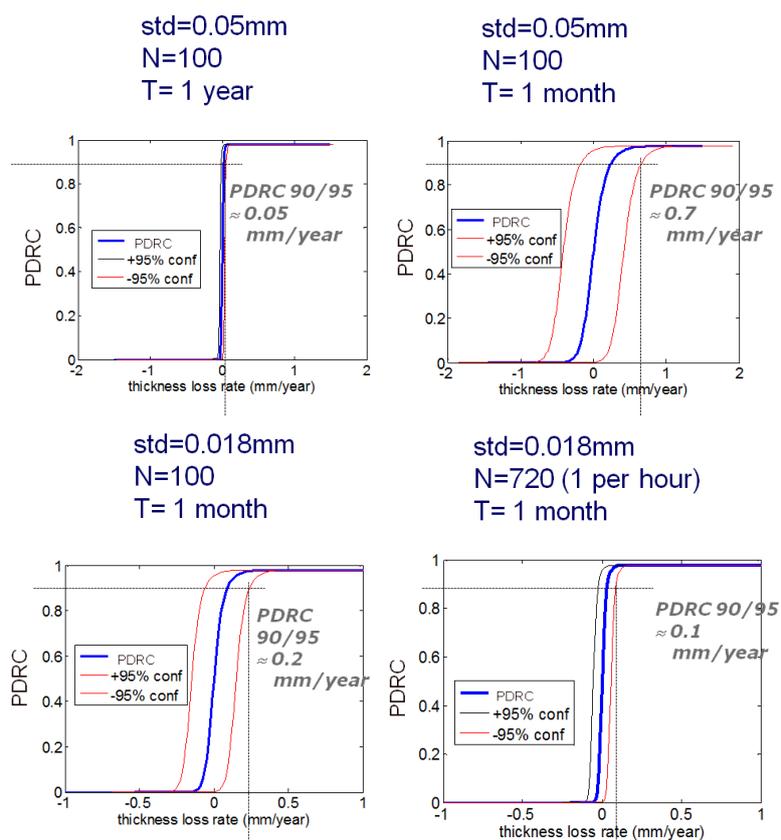


Figure 8: Calculated PDRC for wall thickness slope change detection and 95% confidence intervals for wall thickness measurement standard deviations of 0.05mm (top) and 0.018mm (bottom) and different numbers of measurement period and time period over which the measurements are evaluated. Values are typical of what would be expected for permanently installed ultrasonic thickness gauges.

## CONCLUSION

This work has presented an approach to compare the performance of manual ultrasonic thickness gauging with that of permanently installed sensors with respect to detecting change in wall thicknesses and detecting change in the rate of wall thickness loss. The reduced variability in thickness measurements can make the permanently installed thickness gauges capable of reliably detecting thickness changes an order of magnitude smaller compared to conventional manual ultrasonic thickness gauging methods. The same increased performance is achieved for the detection of wall thickness loss rate (slope) change. It is believed that most of the increase in performance arises from the fact that the permanently installed sensor automates the acquisition procedure and eliminates operator slips/errors associated with probe coupling, setup and result collection/recording. However, it is important to note that the performance of all the ultrasonic techniques (be it manual or automated) is partly influenced by the surface of the component that is measured and uncertainties that are introduced by surface roughness introduced by the corrosion process itself cannot be simply removed. Nonetheless, frequent tracking of the wall thickness undoubtedly can be said to improve estimates of wall thickness trends by an order of magnitude or even more.

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