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Use of water immersion UT techniques to assist with data capture

Wykorzystanie technik zanurzeniowych UT dla optymalizacji akwizycji danych

ABSTRACT

Ascertaining the integrity of large steel structures such as storage tanks, pipes and vessels is a complex task. Silverwing (UK) Ltd have developed an inspection system based on a water immersion UT (ultrasonic testing) approach that can manage, present and generate reports for large volumes of data, from gigabytes to even terabytes that can be obtained from a single asset. This paper explores inspection efficiency at the data capture stage and shows examples towards illustrating how volumes of information is technically handled and how it can improve the efficiency of the overall inspection process, benefiting the inspection company, asset integrity engineer and asset owner.

Keywords: *water immersion UT, tanks automated UT inspection, UT surface discrimination*

STRESZCZENIE

Określenie stanu dużych stalowych elementów takich jak zbiorniki magazynowe, rurociągi oraz zbiorniki ciśnieniowe to złożone zadanie. Firma Silverwing UK LTD opracowała system inspekcji oparty na technice zanurzeniowej UT (badania ultradźwiękowe), który umożliwia akwizycję, zarządzanie danymi oraz generowanie raportów nawet dla bardzo dużych ilości danych, od gigabajtów do nawet terabajtów, otrzymanych podczas badania jednej instalacji. W artykule dokonano oceny wydajności inspekcji na etapie akwizycji danych oraz przedstawiono przykłady przetwarzania różnych ilości danych oraz sposoby optymalizacji procesu inspekcji, na czym zyskają zarówno firmy przeprowadzające inspekcję, inżynierowie odpowiedzialni za stan techniczny oraz właściciele elementów poddawanych inspekcji.

Słowa Kluczowe: *systemy zanurzeniowe UT, zautomatyzowana inspekcja UT zbiorników, rozróżnienie powierzchni przy badaniach UT*

1. Introduction

Several inspection standards which cover the maintenance of large assets frequently state that a relatively small collection of sparsely separated spot-measurements are needed to estimate its remaining life or the interval until the next inspection. The inspection of these large assets can be very time consuming and so a balance is normally derived between the time available to conduct the inspection and the level of measurements required to determine its condition.

Of course, the inspection time can be reduced by only targeting areas of the asset that are normally associated with corrosion, e.g. the product interface level in a storage tank. The complexity of the inspection of such assets is usually derived from a set of guidelines which the asset owner has adopted. EMMUA 159 [1] is one such guideline and by crude approximation, the recommended number of 10 mm2 spot-measurements on a 15 m high shell wall of a storage tank 50 m in diameter would cover approximately 0.0012% of its surface. Unless prior information and location of the critical areas of corrosion is available, the likelihood of finding the corrosion is small. The most obvious improvement is to increase the number of spot-measurement, at the cost of time.

The likelihood of locating corrosion on these structures is highly dependent on the non-destructive testing (NDT) approach used. An automated process to collect spot-measurements can improve the positional accuracy but also increases the number of measurements taken over a given area. With a suitable inspection tool setup, the condition of the internal and external surface, along with inclusions, blistering, dis-bonding of internal liners and even cracking can be found. The umbrella of inspection can arguably be divided into two stages, in-field data acquisition followed by reporting. The basis of this process is shown in Figure 1 beginning with the asset in its normal operating state. Once an inspection is deemed necessary, the two stage inspection process beings. Pending the results of the inspection, repair may or may not be necessary before the asset is re-commissioned (or decommissioned). During inspection the data acquisition and reporting stages can repeat several times, dictated by the analysis of the recorded measurements. This is usually a consequence of fine-tuning the inspection tool setup or deciding to hone in on an area of interest.

Primarily, focus towards driving the efficiency of the inspection process is given to the data acquisition stage by improving the physical speed of the scanner or by creating arrays of sensors to generate a colour coded 2D (X/Y) map of measurements (C-Scans) with one sweep.

It can be argued that the primary goal in this stage is to minimise the operator time in-field and limit the exposure to harsh environments. While such approaches usually result in improved efficiency, little focus is given to the reporting stage. With the ability to capture vast quantities of scan data with the advent of cheap digital storage, the data (or scans) still needs to be labelled, sorted, 'stitched' together, analysed and its key findings consolidated into a final report.

The reporting stage is normally underestimated and normally

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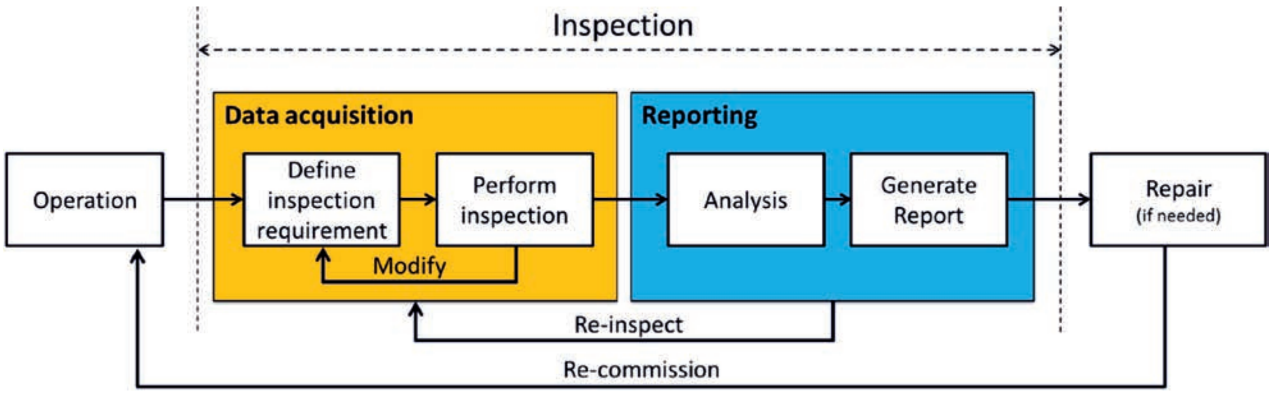

Fig. 1. High-level representation of the inspection process
Rys. 1. Zobrazowanie procesu inspekcji

involves a combination of spread sheet, word processing and image manipulation software that can be a process just as time-consuming as the first. This paper examines the efficiency of data acquisition stage.

2. Data acquisition stage

There are a myriad of tools available to inspect large areas and perform remote measurements with different inspection instruments, one common form is the deployment of ultrasonic probes. Silverwing (UK) Ltd has an automated inspection tool that is able to perform UT that can cover the vast majority of an assets surface and is able to record millions of spot-measurements, normally referred to as automated UT (AUT). These devices cover relatively small areas and so adjacent scans are conducted in order to cover a larger area. Sometimes the scans are overlapped to aid alignment (the 'stitching' process) during the reporting stage; a topic discussed towards the end of this paper.

The AUT system offered by Silverwing (UK) Ltd uses an immersion approach that utilises a column of water to couple the sound generated by the probe and the surface under inspection. The water column is contained in a 'probe holder' that is continually fed to overcome water dissipation as the probe travels across the surface. The volume of water lost is subject to changes in the surface of the asset. Even if coated, a breakdown can cause an assets wall to be subjected to the environment, eventually resulting in corrosion. In this section, three small case studies are presented that demonstrate the capability of the AUT approach focusing on the following parameters:

- water immersion and surface discrimination,;
- scan resolution;
- amplitude monitoring.

Water immersion and surface discrimination

With the water immersion UT approach, there is a distinct advantage as additional information beyond material thickness can be obtained such as the profile of the near-surface. The water column, between the UT probe and near-surface can vary in the presence of flaws or corrosion. Changing the path length of the water causes the surface interface signal of the UT to vary, indicating the presence of near-surface variation. Coupled with traditional back-wall echo measurements and an additional gate fixed to a single point in time on the UT to track the variation of the interface, changes to the water column length can be monitored, indicating the presence of wall loss on internal, external or even on both. An example scan of a section of pipe is shown in Figure 2, illustrating a large artificial flaw on the internal surface (a) and three artificial flaws on the near-surface (b) on which the AUT scanner resides. UT signals from the immersion approach can be seen to contain more information than traditional contact probes.

The associated UT thickness map of the flaws shown in Figure 2 (a) and (b) is shown in (c), illustrating a colour coded representation of the thickness of the material. Green relates to the nominal thickness of the pipe, tending from green then yellow through to orange as the material becomes thinner. Peering through the surface of the material with map (c) illustrates the location of the large defect in the centre and also the corresponding defects (i), (ii) and (iii) shown in Figure 2 (b). The near-surface flaws shown in Figure 2 (b) are reported in (d) without the indication of the internal surface flaw illustrating discrimination. Further detail of this approach can be found in [2].

While discrimination is a major benefit there are other parameters to consider with the immersion approach. Along with crystal frequency of the probe plays an important part in the definition of the thickness measurement, the probes focal length is a parameter to consider. With the immersion approach, the focal point is a combination of the path length of the water column and the thickness of material being inspected. Depending on the requirement, the focal point can be chosen to focus on the internal surface to look for flaws or in the centre of the material to observe laminations or inclusions.

Scan resolution

A raster scanning AUT system allows the resolution of spot-measurements to be tailored. Each spot-measurement is typically defined by a square area such as 10 mm x 10 mm and even down to high-resolutions of 0.5 mm x 0.5 mm or less. The choice in resolution is a compromise between the time available to conduct the inspection and the largest discontinuity that the asset owner is willing to miss. When planning the inspection, risks are calculated based on many other factors including, the already mentioned asset history, the assets location (environment), information about neighbouring assets, the timeliness to get the asset back in-service and the approach used to perform the inspection. Some efficiency gain can be achieved by first scanning the majority of an assets surface at a coarse resolution, for example 20 mm x 20 mm or 50 mm x 50 mm. From these scans, corrections to the inspection requirement may then follow based on unforeseen circumstances or located areas of interest with a more detailed inspection, e.g. re-scanning areas of interest a second time at a higher resolution.

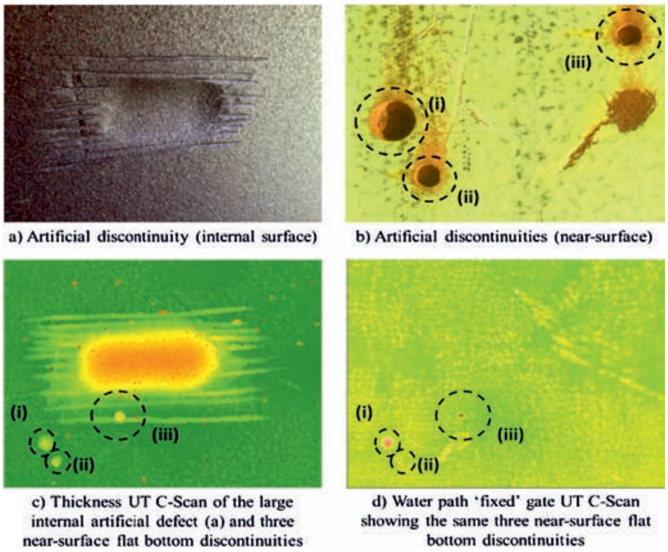

Fig. 2. Example internal and external flaws and their associated top surface and material thickness maps via UT
Rys. 2. Przykłady wewnętrznych i zewnętrznych wad oraz odpowiadających im map powierzchni i grubości materiału zarejestrowanych przez system UT

To illustrate the potential danger of this approach, an AUT inspection has been conducted with a set of artificial defects and their corresponding C-Scans are shown in Figure 3. In this example, the data acquisition has been repeated with four different resolutions starting with a coarse resolution of 50 mm x 50 mm in (a) and increasing the resolution down to 1 mm x 1mm in (d). It is clear that from the pixelated representation in (a), the increased resolution improves the definition and shape representation of the defects. It is also apparent that the two smaller circular defects and diagonal grind marks shown in (c) and (d) are missing in (a) and only partially represented in (c). Based on the defects illustrated in this example, scan (b) represents the minimal resolution necessary to find the defects. Even so, this is again a compromise as the shape of the diagonal grinds could be misinterpreted as individual narrow defects, only at higher resolutions are their shapes identified.

Ideally, if the inspection equipment were able to perform the inspection at the same speed regardless of resolution then the smallest resolution would be chosen as digital storage is available at relatively low cost. Negating phased array type systems, traditional AUT systems normally comprise of a single transducer that is driven in a raster manner to generate the C-Scan images. As the resolution increases, the number of samples required per second increases as do the number of raster sweeps. This gives an exponential style increase of time required to scan as a function of resolution. At a high resolution of 0.5 mm, the time taken to conduct a scan is approximately 144 minutes. This time decays in an exponential manner as the resolution decreases and down to 1 minute for a resolution of 50 mm. For the corresponding defects, the smallest diameter that could be found as from a choice of scan resolutions is represented by the logarithmic style plots. The red plot depicts the absolute smallest defect diameter that could be found for a given resolution and is based on the Nyquist sampling rate which states that the sampling rate must be two times higher than the highest frequency to observe. In this context, the highest frequency relates to the smallest defect diameter. Under this sampling theorem, the smallest defect that could be reliably observed at a 0.5 mm resolution is 1mm, at 2 mm it would be a diameter of 4 and so on; double the chosen resolution.

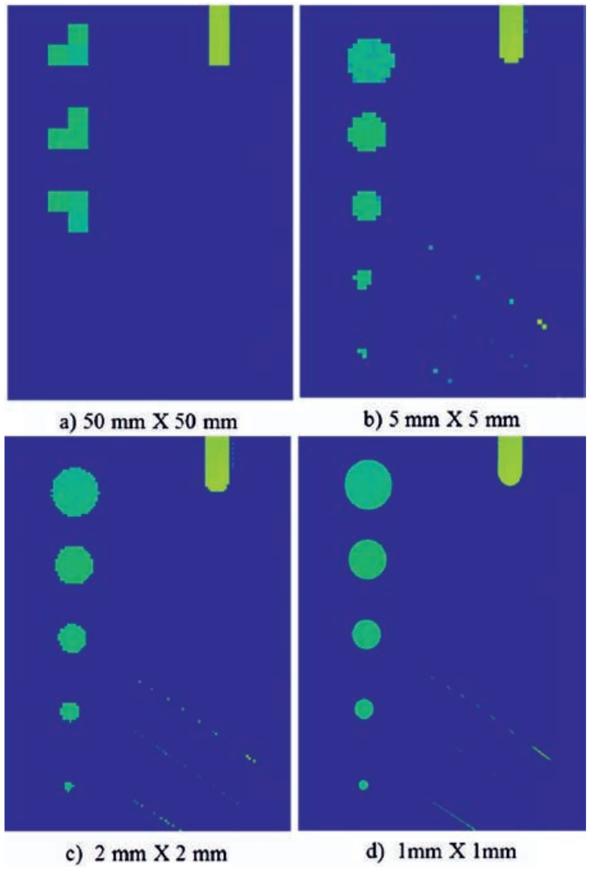

Fig. 3. C-Scans of a set of artificial defects at four different resolutions. Notice that as the resolution decreases towards 50mm x 50mm, a number of smaller discontinuities have been missed
Rys. 3. C-Skany sztucznych wad zarejestrowane przy badaniu z czterema różnymi rozdzielczościami. Należy zwrócić uwagę na to, że zmniejszając rozdzielczość do 50 x 50 mm, nie wykryto kilku mniejszych nieciągłości

This is also under the assumption that these defects are flat-bottom. Another condition is that the Nyquist sampling rate applies to period signals, not discontinuous ones like defects and so to obtain a reasonable estimate of a defect size a typical engineering 'rule-of-thumb' approximation of the sampling resolution should be 10 times that of defect diameter that needs to be located and profiled. This is illustrated by the green profile in Figure 4 and clearly demonstrates the impact that scan resolution can have on the ability of AUT.

However, there are other parameters that can be considered to aid the efficiency. One considers the beam spread at the focal point of the UT probe. Depending on the focal spot, the beam spread can cover an area in the region of mm2 and so scan resolutions that are higher than the focal point can be considered excessive.

Another compromise relates to perform data acquisition with a coarse resolution to first locate defects, followed by higher resolution scans of located defects in order to size them. One caveat with this approach is that the coarse resolution chosen must, at the very minimum adhere to Nyquist sampling rate.

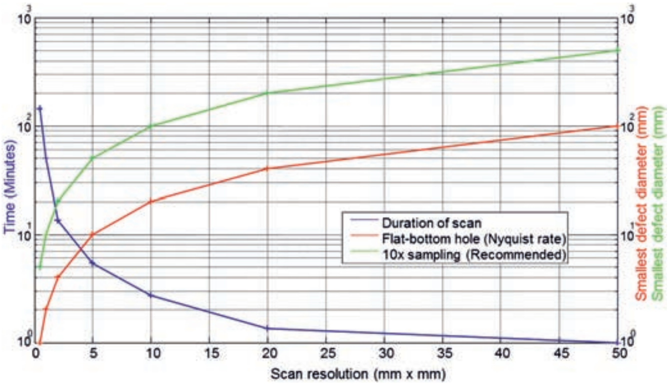

Fig. 4. The time required to perform a scan at a variety of resolutions (blue). The diameter of defect that can be located at a given resolution is also shown, one adhering to the Nyqusit sampling rate and the other based on a recommended ‘rule-of-thumb’ sampling rate of 10

Rys. 4. Czas potrzebny na wykonanie skanu przy różnych rozdzielczościach (niebieski). Dodatkowo zobrazowano wielkość wady, która może zostać zlokalizowany przy określonej rozdzielczości, stosując się do współczynnika próbkowania Nyqusita (czerwony) oraz w oparciu o stosowaną w praktyce zasadę współczynnika próbkowania 10 (zielony)

Amplitude monitoring

Traditionally, AUT systems are utilised to determine the condition of an assets structure by measuring its thickness by configuring a set of gates over a UT signal. These gates can have several functions, they can measure the flank of each echo (the first point which crosses the gate in time), the time at which the peak amplitude of the echo is located or from a fixed position in time (as shown earlier to discriminate near-surface flaws). A gate can also be used to monitor the amplitude of a given echo. This can provide further information about the condition of the asset by indicating regions of poor reflectors caused by the sound scattering. As the amplitude of these echoes is a function of the reflecting UT signal, then the edges of defects and those with low amplitudes that make gate measurements difficult can be clearly shown on the corresponding C-Scan. Monitoring the amplitude of an echo can also be used to assess the condition of an internal rubber bonded liner. In the region of a bonded area, the acoustic impedance is less and so the sound travels through asset material, into the adhesive bond and into the liner, absorbing the sound energy and limiting the amount of reflection.

The interface between the internal of an assets surface and an un-bonded area has higher acoustic impedance, thus giving a reflection with higher amplitude. The discrimination of a bonded and un-bonded area with AUT and an amplitude gate configuration is shown in Figure 5. This is a C-Scan of an area of a 16 mm nominal thickness pipe with an internal rubber coating 11 mm thick. The bonded area of rubber is identified by the low amplitude signals, shown here by the red region. The corresponding un-bonded are is shown with higher amplitudes in yellow. The aim here would be to locate any regions of high amplitude (yellow) in the bonded areas and identify regions where the lining or glue had perished. It is also interesting to see additional information in this scan by the location of the glue overspill area. As the liner was applied, the bonded area was pressed on top of some adhesive at such pressure, the remainder of the glue was forced out the side, resulting in the overspill area. This is made visible by the trace at the edge of the glue, shown here in red, which also causes the amplitude to drop based on the refraction and scattering of sound.

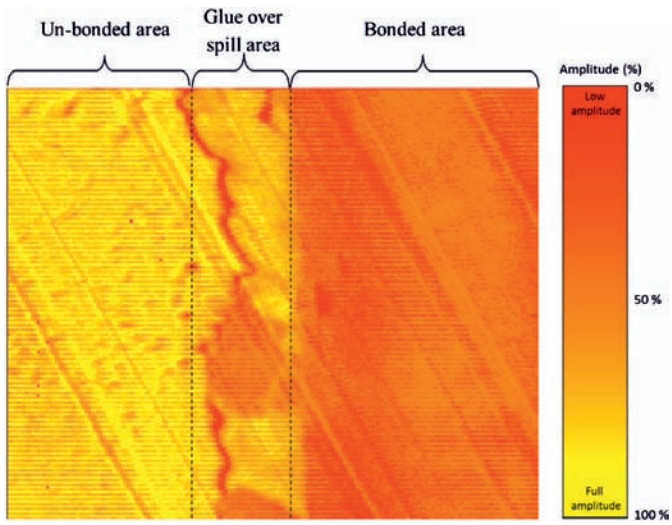

Fig. 5. Amplitude map of a back-wall echo showing bonded, unbonded and glue line of an internal rubber liner in the internal surface of a pipe

Rys. 5. Mapa amplitudy echa dna pokazująca materiał połączony, niepołączony oraz linię klejenia wkładki gumowej znajdującej się na wewnętrznej powierzchni rury

The case studies of the three parameters presented here demonstrates advantages of the AUT approach and considerations when planning the inspection. Efficiency in the form of time can be chosen at the cost of likelihood of locating a defect in the data acquisition stage.

3. Conclusion

Efficiency of the inspection process is always improving, usually through faster scanning equipment. It then follows that faster scanning can result in more data and while it is generally accepted that more useful data can reveal further details about an assets integrity, more data can also lead to challenges downstream during the analysis. In this paper, we have described being able to obtain more asset information through extra gates and the surface location of defect without impacting on efficiency or tailoring the time taken to inspect by adjusting scan resolutions.

4. Acknowledgments

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