Monitoring of Engineering Assets using Ultrasonic Guided Waves

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Abstract. The principle of using low frequency guided ultrasonic waves for screening long lengths of pipe for metal loss defects has become well established, and there is a growing acceptance of the technique as a means of rapid survey of pipework systems. This paper builds on the increasing field experience with this test method and examines the possibilities of examination of other product types. The technology is being developed via a European Union Collective project involving seven Industry Association Groups. A significant part of this work is to develop a Europe-wide training and certification network for personnel using ultrasonic guided waves.

1. Introduction

The low frequency ultrasonic guided wave technique has been developed for the rapid survey of pipes, for the detection of both internal and external corrosion. The propagation of the so-called guided waves is affected by changes in thickness of the component, so that they are sensitive to metal loss defects, notably corrosion. The principal advantage is that long lengths, 30m (~100ft) or more in each direction, may be examined from a single test point. The benefits are:

- Reduction in the costs of gaining access to the pipes for inspection, avoidance of removal and reinstatement of insulation (where present), except for the area on which the transducers are mounted,
- The ability to inspect inaccessible areas, such as under clamps and sleeved or buried pipes,
- The whole pipe wall is tested, thereby achieving a 100% examination.

Site trials have demonstrated that this method is capable of detecting corrosion <30% wall thickness deep and <25% circumference wide. The technique is now commercially available as an inspection tool for use in hydrocarbons transmission and processing facilities.

The impetus for the use of long range ultrasonics is that ultrasonic thickness checks for metal loss due to corrosion or erosion are highly localised, in that they only measure the thickness of the area under the transducer itself. To survey a large area requires many measurements and access to much of the surface of the component being examined. Where access is difficult or costly a detailed survey becomes unattractive economically, with the result that often limited sampling only is carried out. Similar restrictions also apply to other methods of measuring wall thickness, such as radiography, eddy currents etc. Partial inspection of this type is not likely to be effective in reducing the numbers of significant defects which may cause leaks or failure being present in pipes as the probability of detection of defects in uninspected areas is zero. The benefit of using long range testing to examine 100% of the pipe wall along the length tested is therefore considerable. Evidence for this is provided by a study carried out by the UK Health and Safety Executive (Patel and Rudlin [1]), which reported that over 60% of the reportable hydrocarbon release incidents from offshore platforms in the UK North Sea sector were related to pipework. The adoption of adequate inspection and maintenance practices for pipework therefore has a considerable effect on the incidence of both unscheduled plant down-time and leaks of potentially hazardous materials. The use of long range ultrasonics to ensure that the whole pipe wall volume is tested provides a commercially attractive means of improving coverage.

This paper reviews the current situation regarding the performance of long range testing using ultrasonic guided waves and presents the developments currently being carried out under an EU funded Collective project:- ‘Long Range Ultrasonic Condition Monitoring of Engineering Assets’ (LRUCM).

2. Current Status of Guided Wave Testing

Within the past 10 to 15 years a considerable amount of work has been done on the properties and use of ultrasonic guided waves for inspection of both plates and pipes [2-5]. This has led to a high level of understanding of the characteristics of these wave systems and their performance. For example, TWI has been involved in controlled studies of performance, leading to the generation of experimental probability of detection (PoD) data for guided wave tests in pipes, Fig.1. The plateau, where detection is virtually guaranteed, is reached at approximately 400mm^2. The PoD has dropped to around 75% at 200mm^2 and 50% at 100mm^2.

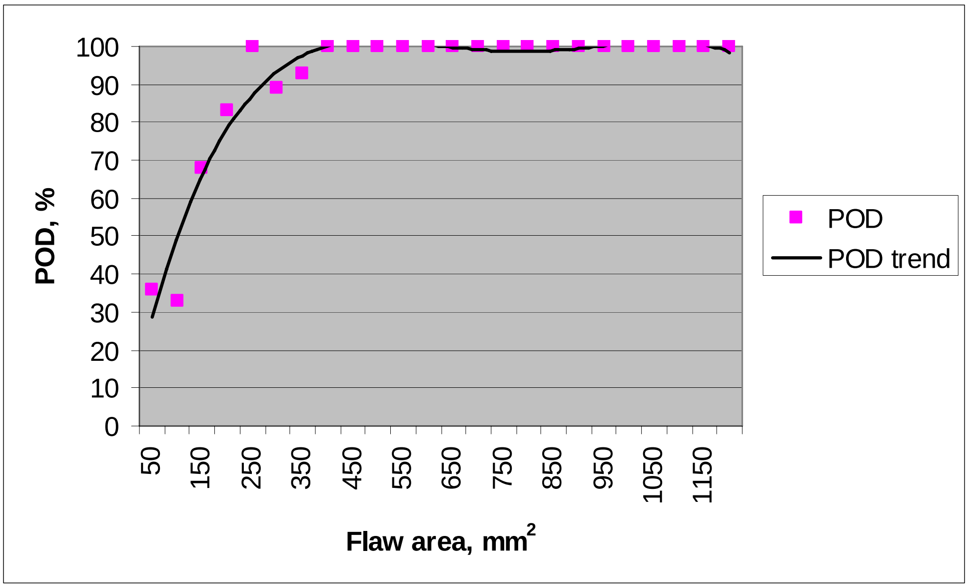

Fig. 1. Experimental probability of detection (PoD) for guided wave tests

It should be noted that all commercially available guided wave test systems transmit axially-symmetric annular waves which sweep along the pipe. The extent to which this wave interacts with an area of metal loss is determined by its depth and the circumferential extent. The detection capability is therefore governed by this cross-sectional area of the defect. From this, it may be seen that these techniques do not give a direct measurement of the remaining wall thickness, so cannot currently be used to provide a replacement for conventional thickness gauging. Equally, whilst there is a relationship between overall defect area and the amplitude of a reflection from it, this relationship is greatly affected by the shape and roughness of the defect itself and cannot be relied upon to predict severity. This limits the current techniques to detection of suspect areas for follow up activity by other methods.

Other factors which impose restrictions on the capability of long range guided wave testing are:

- Complexity of the wave mode system. Under most conditions more than one ultrasonic wave mode exists. These modes each travel at different velocities and many exhibit dispersive behaviour, i.e. the wave velocity varies with frequency, all of which makes interpretation of the resulting test signals difficult,
- Limitations of sensitivity. Where a large volume of material is tested from a single location, as is the case with long range ultrasonics, it is inevitable that the sensitivity and resolution will not be as good as a local test where the material directly underneath the test head is examined. This limits the size of discontinuity which can be reliably detected,
- Attenuation and scattering of the ultrasonic energy by surrounding material. This is due to losses caused by the ultrasonic energy leaking out of the plate or pipe and may include the influence of coatings and, in the case of items buried in the ground – either pipes or sheet piling – the effect of the soil in contact with the surface,
- Component complexity. This generally causes mode conversions, resulting in useful energy from the controlled transmitting transducer being dissipated into other wave modes and thus generating a noise signal which reduces sensitivity and may mask signals from discontinuities. Such effects include bends in pipes and heat exchanger tubes, the shape of railway rails and the multi-strands in wire ropes,
- Lack of qualified test operators. This technology is new compared with other main NDT methods. Consequently, the uptake of the technology is slowed by the non-availability of a large pool of suitably qualified personnel. This in turn is caused by the lack of standardised procedures and training and certification schemes

3. Development Strategy within the LRUCM Project

The LRUCM project aims to take this technology forward in three main areas:-

- Improvement in the test range and sensitivity for pipe inspection,
- Extension of the application of long range inspection using guided waves to other product types, namely, heat exchanger tubes, railway rails, wire ropes and plate/sheet components,
- Development of training and certification schemes for personnel using guided wave techniques.

The project will also develop techniques for long term structural monitoring an addition to one-off inspections.

A key element in the improvement in test performance is the ability to use the transducer tool as a phased array to allow the energy to be focused at the defect location, Fig.2. This enables the sensitivity to be improved and the lateral dimension of the flaw to be determined. The focus is achieved by applying different signals to the segments in the tool array. This focus may be positioned at a specific distance from the tool and may be scanned around the pipe by adjusting the excitation parameters for each segment. The tool remains static throughout the operation.

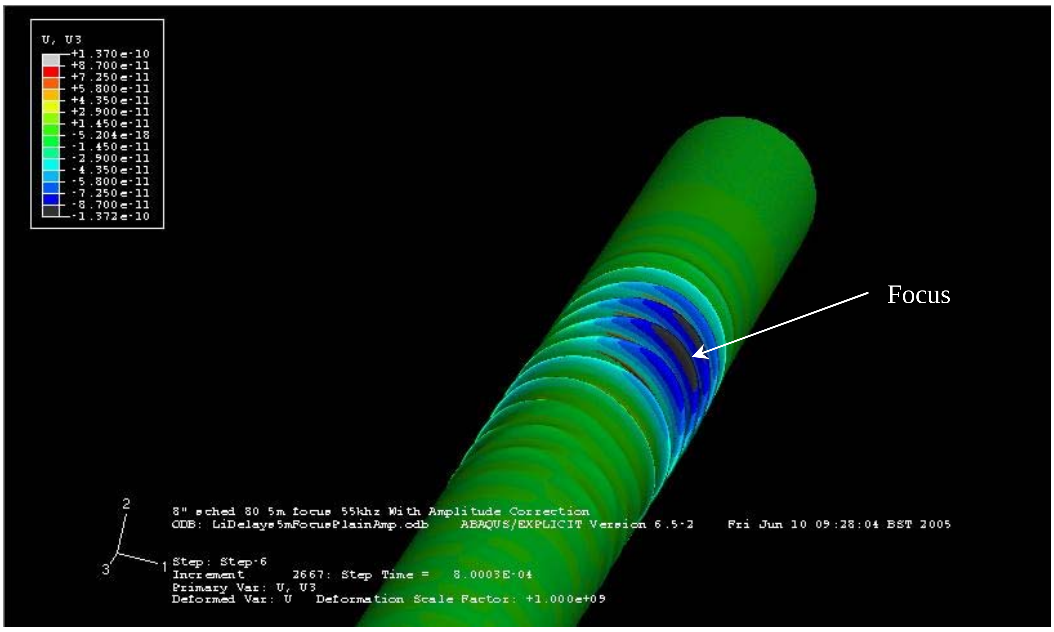

Fig. 2 Finite element model of the focus (at 45º) of ultrasonic guided waves in an 8” pipe

The concentration of the ultrasonic energy on a small section of the circumference increases the local sensitivity and therefore allows smaller defects to be detected. The ability to ‘scan’ the focal spot around and along the pipe enables circumferential position as well as distance from the tool to be determined. The data may be plotted as a C-scan development of the pipe, thereby providing a map of any metal loss. This method has been applied to a 195mm^2 calibration notch at the 12 o’clock position in a 10” (273mm) diameter pipe. The resulting display is shown in Fig.3.

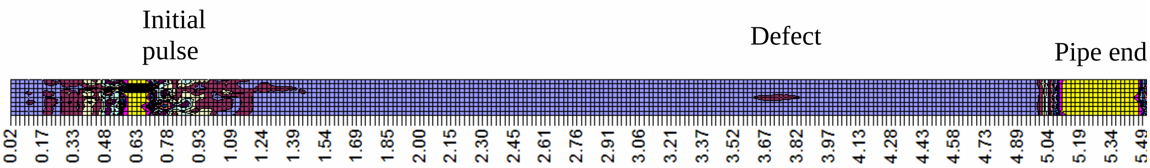

Fig.3. C-san plot of 195mm^2 defect at the 12 o’clock position in a 10” pipe

The data may also be plotted as an isometric display, which gives a clearer understanding of the signal to noise ratio for the test. The detection capability is often expressed in terms of the signal to noise ratio for a given defect. Figure 4 shows the response from the 195 mm^2 defect when focusing is applied. The signal to noise ratio increases from 12 dB (a factor of 4) to 20dB (a factor of 10) after focusing. Application of focusing in this way increases the PoD for defects of this size from 75% to 100% and reduces the threshold where 100% detection is achieved from 400 mm^2 to 100 mm^2 .

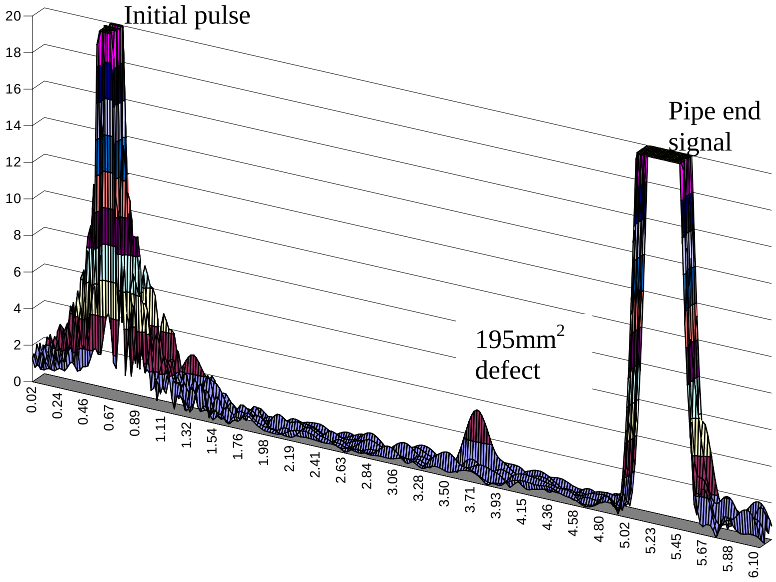

Fig. 4. Response from a 195mm^2 defect in a 10” (273mm) diameter pipe after focusing

Focusing of the energy and the availability of the lateral dimension provides the potential for producing a size estimation for the defect. A second deliverable from the project is a means of determining defect size from guided wave data, which will allow plant owners to assess severity of defects in inaccessible sections or components. The aim is to provide at least sufficient information to determine whether action to repair or replace the component must be taken immediately, or whether it may be left in service for a further inspection interval.

In parallel with this, studies are underway to determine the mechanisms of attenuation from coatings, so that the attenuating effects may be overcome.

4. Training and Certification

A very major part of the LRUCM project is an awareness programme which will enable the European inspection industry to make the maximum use of the benefits of using guided wave testing. This has three aspects:-

- Awareness workshops for both SME inspection service providers and plant owner/operators to raise the level of understanding of guided wave inspections,
- Development of training material for inspection personnel involved in guided wave testing,

– Development of a training and certification programme, based on European (EN473) and international (ISO9072) standards to enable customers of guided wave inspection services to have confidence in the application of the technique.

These activities will be delivered by the seven Industry Association Groups (IAGs) in the project consortium, so that there will be international and multi-lingual dimensions to the output from the project. It is anticipated that there will be local delivery of courses and examinations via the various national NDT societies.

5. Project Outcomes

The main outcomes from the LRUCM project are:-

- Training course syllabus and materials, course notes and other training material,
- A library of specimens for training purposes,
- Training courses – delivered via the NDT societies
- Certification examinations – delivered by the NDT societies,
- Awareness campaigns for end users (plant owners/operators),
- Demonstration of improvements to the guided wave techniques generated in the project,
- Dissemination of information via relevant inspection conferences,
- Guideline documents for the use of long range guided wave testing,
- Involvement in standards committees.

6. References

[1] Patel R and Rudlin J, 'Analysis of corrosion/erosion incidents in offshore process plant, and implications for non-destructive testing' Insight - Journal of the British Institute of NDT, Vol 42 No.1, January 2000.

[2] Cawley P & Alleyne DN, 'The use of Lamb Waves for the Long-Range Inspection of Large Structures', Proceedings of Ultrasonics International 95, published in Ultrasonics, Vol. 34, pp287-290, 1996.

[3] Kwun H, Kim SY and Light GM, 'Long-Range Guided Wave Inspection of Structures Using the Magnetostrictive Sensor', Journal of the Korean Society of NDT, Vol. 21, pp383 – 390, 2001.

[4] Rose JL, 'A baseline and vision of ultrasonic guided wave inspection potential', Journal of Pressure Vessel Technology, Aug. 2002, 273 – 282

[5] Mudge PJ, 'Practical Enhancements Achievable in Long Range Ultrasonic Testing by Exploiting the Properties of Guided Waves', proceedings of the 16th World Conference on NDT, Montreal, Canada, September 2004.