

Improvements to the performance of guided wave testing on coated and buried pipes

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Abstract

Ultrasonic guided wave testing has become an established method for testing long lengths of pipes economically from a limited number of test locations. Conveniently, regions that are hard to access, such as spans over roads or rivers, in culverts or where pipes enter the ground, may be inspected from adjacent positions which may be reached more easily. However, where pipes are buried or are in other areas where corrosion may be severe the pipe, which is almost always ferritic steel, is normally protected by a barrier coating on the outside. These coatings are usually viscoelastic in nature. The mechanical properties are such that they readily absorb elastic ultrasonic vibrations, so that the attenuation rates for guided waves transmitted along the pipe are considerably higher than for bare pipe. This increased rate of signal loss significantly reduces the usable test range. In addition, the background noise on the signals tends to be greater than for bare pipe, thereby reducing sensitivity to defects, so that the use of guided wave testing becomes less attractive as an inspection option. An extensive programme of work has been carried out by Plant Integrity Ltd, Brunel University Innovation Centre and Applied Inspection Ltd to address this issue. A combination of model-led procedural enhancements, improved instrumentation functions and novel signal post-processing has been shown to achieve considerable improvements to both test range and sensitivity to defects in coated and buried pipes. Results are presented to demonstrate the improvement in performance achieved.

1. Introduction

Ultrasonic guided wave testing of steel pipelines is normally based on a pulse-echo principle, and the technique is highly successful for pipelines that are uncoated and unburied where attenuation of the guided waves is low (1-4). However, where pipes have a protective coating, the coating material is normally viscoelastic and absorbs sound energy and, if the pipeline is also buried, sound energy can also leak into the surrounding medium causing further losses. In both cases, attenuation of guided waves is high (of the order of several dB per metre) in the usual long range ultrasonic testing frequency range from 20kHz to 100kHz and the effective test range is thus significantly reduced. Furthermore, in addition to the reduction in signal strength, the background noise level can also increase, especially for coating materials that have been present on the pipe for a number of years. In this case, bonding conditions between the coating material and the pipe substrate become uneven due to pressure changes and temperature variations around the pipe etc., and noise signals are created by scattering and mode conversion. This has an impact on the sensitivity of the test to defects compared with guided wave tests on uncoated pipe. To maintain sensitivity it is necessary to identify

small signals that may be within the noise floor and signal interpretation is very challenging, because of the complexity of the noise signature. In particular, the issue of detection of corrosion in coated and buried lines has been identified as major factor affecting plant availability in the nuclear power industry, where the condition of buried ancillary and emergency cooling water pipes may cause power generation to be shut down for safety reasons.

The aim of this work was to investigate the improvements which could be made to the test range and sensitivity to defects of guided wave tests on coated and buried pipe by means of determining the effect of the coating on guided wave propagation by modelling, making improvements to both instrumentation and test procedures based on the modelling results and improving the signal quality by post-processing of the received signals.

2. Technique Development

2.1 Determination of coating properties

Commercial guided wave systems for pipe inspection generally operate by transmitting an axisymmetric wave mode, either T(0,1) or L(0,2), along the pipe at a frequency which gives a frequency \times thickness product less than 1 mm.MHz. In bare pipes such waves propagate with an attenuation rate little greater than the intrinsic attenuation for elastic waves in steel of approximately 0.2dB/m. While it is accepted anecdotally that viscoelastic coatings attenuate guided waves at a greater rate than this, there is hardly any useful quantitative data available for the actual attenuation rate caused by such coatings. One facet of the project was therefore to obtain realistic values for the relevant acoustic properties of the coating to be studied. For this work the widely-used Denso tape (Winn & Coales International Ltd) was used, as it is easily applied as a spiral wrap for experimentation. A combination of a previously-developed semi-analytical finite element (SAFE) model (5) and experimentation was used to determine the effect of the coating on the propagation of the T(0,1) and L(0,2) guided wave modes.

For the experiments a *Teletest* guided wave unit was used to generate and receive signals. The *Teletest* transducer was located 2.5m from one end of a 5.8m long 6" schedule 40 pipe. The pipe was supported by two pipe supports with foam inserted between the pipe and the supports to avoid scattering of elastic waves from the contact points. A 2m length was coated with Denso tape. The coating was 2.5mm thick. The experimental set up is shown in Figure 1.

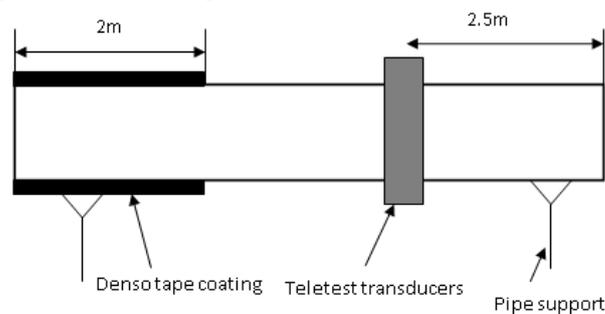


Figure 1. Experimental set up on a 5.8m length of 6" (168mm) diameter,

schedule 40 (7.11mm thick) steel pipe (6).

Both T(0,1) and L(0,2) were used as the incident modes. The attenuation of these two modes was then measured. It was assumed that the uncoated section of the pipe does not absorb sound energy and that the attenuation is only caused by the coating material. The attenuation of T(0,1) is only related to the shear properties of the coating, while the attenuation of L(0,2) is also related to the longitudinal (compression) properties of the coating. These two modes are thus enough to extract bulk material properties of the coating. With the transducers fixed at the location shown in Figure 1, two different methods were used to measure attenuation of these two modes, the first with the sound being transmitted in both directions along the pipe and the second with the sound transmitted in one direction only. This is possible because the *Teletest* unit allows the direction of the incident mode to be controlled, using a multi-ring transducer system.

To extract these material properties, a trial and error procedure was used by gradually modifying the material properties in the SAFE model, until a good fit was found between the theoretical model and the measurements for the two modes at all the frequencies. This was carried out by comparing attenuation ratio of T(0,1) first, because the attenuation of T(0,1) is only determined by the shearing properties. After this, the attenuation of L(0,2) can be used to infer longitudinal properties of the coating. This process is described in more detail in (6). Following this procedure, the extracted material properties for the Denso tape coating are as given in Table 1.

Table 1. Acoustic properties for the Denso wrap (6)

Transverse phase velocity, c'_T	200 m/s
Transverse attenuation coefficient, a_T	5.1×10^{-3} s/m*
Longitudinal phase velocity, c'_L	1300 m/s
Longitudinal attenuation coefficient, a_L	1.2×10^{-3} s/m*

* Units are seconds/metre – this gives a frequency-independent value

The method also allowed the predicted attenuation rates for the two modes in Denso coated pipe to be compared with measured values. The results are shown in Figure 2. These indicate good agreement between the predicted and measured values which suggests that the modelling method is a good means of predicting the influence of coating on the practical test performance.

The results in Figure 2 show that there is an intrinsically lower attenuating effect for the L(0,2) mode than the T(0,1) mode and that, for both modes there is a small influence of frequency in the range studied for this particular type of coating. However, it should be noted that this behaviour is heavily dependent on the coating acoustic properties and on the coating thickness. The importance of this information about coating properties is that it may be used to select optimised testing conditions, such as frequency, if the coating shows high frequency dependence on attenuation. It is also worthy of note that the L(0,2) mode has an intrinsically lower attenuation characteristic for the coating studied, so is likely to achieve longer test range. It must, however, be borne in mind that this mode also scatters more easily, thereby increasing baseline noise, so that the overall effect on test performance will have to be evaluated.

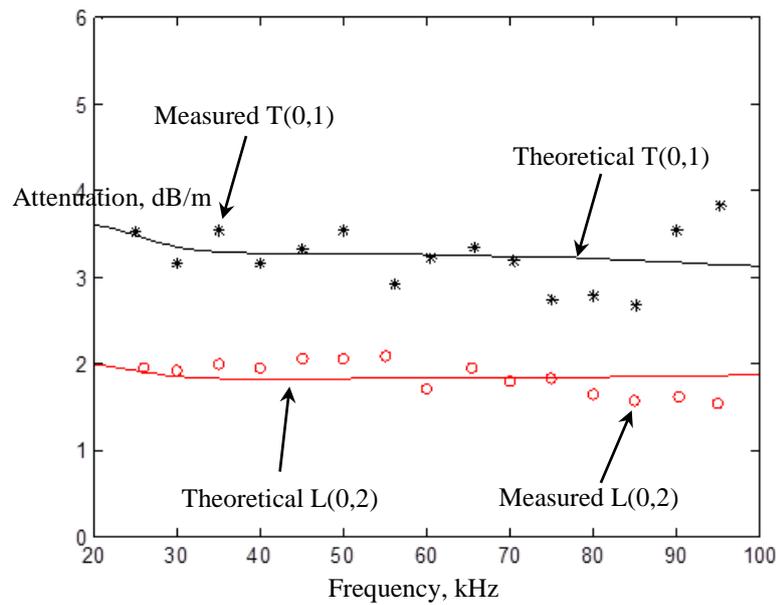


Figure 2. Attenuation of T(0,1) and L(0,2) with frequency for the Denso tape coated pipe (6).

2.2 Procedure enhancements

For practical testing of pipes with highly attenuating coatings there are two main considerations. First, the rate of attenuation gives rise to a very wide range of amplitudes in the received signals along the test length, which is potentially many metres. For example, on a bare pipe with an attenuation rate of 0.2dB/m an ultrasonic signal with an initial value of unity will have an amplitude of 0.8 after 10m propagation. For an attenuation rate of 1dB/m the amplitude after 10m will be 0.3, for 3dB/m (the value obtained for T(0,1) for Denso coated pipe in Figure 2), the amplitude will be 0.03 and for 6dB/m the amplitude will be 0.001, i.e. 1/1000 of the initial amplitude.

This situation is exacerbated if part of the pipe is uncoated with a portion that has a coating present, for example where a bare pipe entering a buried section which is coated and required to be inspected. The above values indicate that for any reflectors in the uncoated section the response amplitudes will be of the same order as the transmitted ultrasound, whereas responses from the coated part are likely to be several orders of magnitude lower. The challenge is for the guided wave instrumentation to be sensitive to the small signals while not overloading the amplification stages with the comparatively very large signals from the low attenuation region and causing the signals to clip. The test procedure therefore needs to ensure that the dynamic range of the responses is controlled as much as possible. Figure 3 shows a test specimen, ‘pipe C’ which was an 8” schedule 40 steel pipe (219mm diameter, 8.18mm wall) partly coated with Denso tape to simulate the transition from an unburied to a buried section, which was used to illustrate this effect.

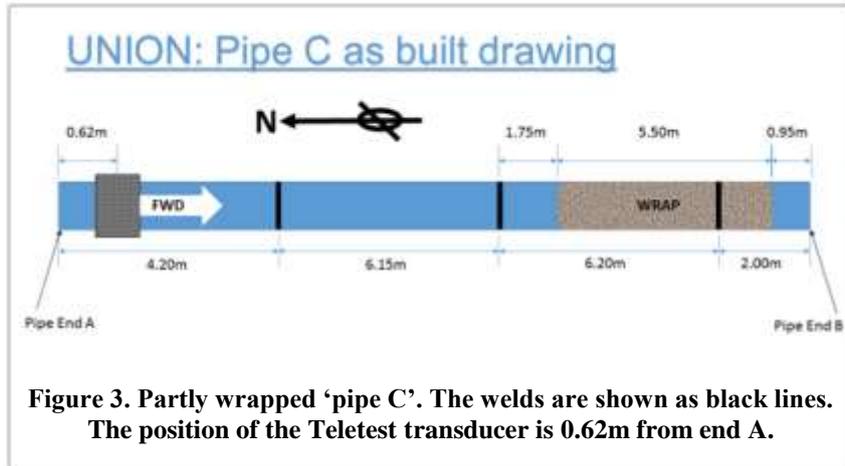


Figure 4 shows the effect of adding a delay to the start of the data collection in order to reduce the total dynamic range of the responses from features of the pipe. The results are for a 35kHz pulse-echo test with the transducer at the position shown in Figure 3. Figure 4a shows the result when no delay was applied. The amplitudes of welds 1 and 2 are 280 and 240mV respectively. The responses from weld 3, which lies under the wrap, and pipe end B are barely visible. The full-scale value is 353mV. By introducing a 16m delay before the start of the data collection, the high amplitude welds in the uncoated part of the pipe can be removed from the data and a much higher sensitivity may be used without the signals becoming clipped and distorted. Figure 4b has a vertical scale of 31mV and the responses from weld 3 (7mV) and pipe end B (12mV) may now be clearly distinguished. The response from weld 3 is 32 dB below that of weld 1. Note, in Figure 4a the responses at 8.5 and 15m are multiple reflections from welds 1 and 2 respectively. In Figure 4b a longer data collection end point was used, so that a multiple reflection from the pipe end was included in the trace.

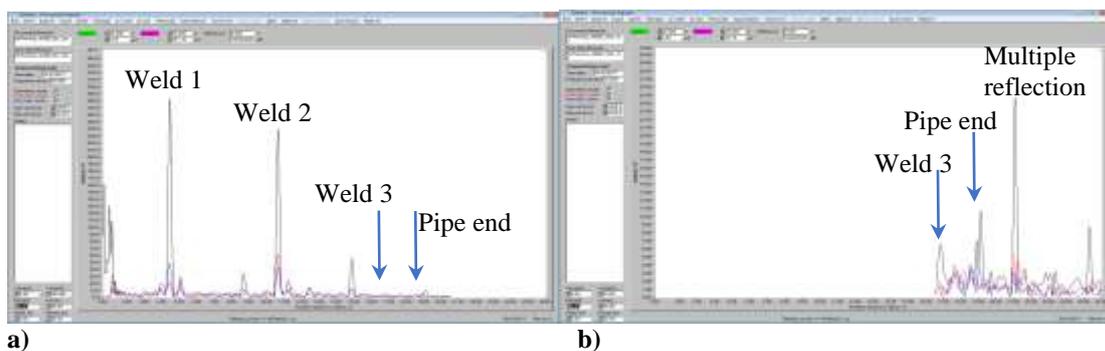


Figure 4. Teletest responses from pipe C in Figure 3; a) with no delay applied, b) with a 16m delay before data collection commenced.

A second factor that affects the results from guided wave tests on coated pipes is the level of scattering observed on the traces. This reduces the signal to noise ratio (SNR) and hence reduces the sensitivity to defects. The SNR around weld 3 is approximately 6dB as may be seen in Figure 4b, which is poorer than expected for guided wave tests on uncoated pipe. This level of background noise is somewhat surprising. Theoretical studies show that coatings will increase the attenuation rate, but should not increase the scatter compared with bare pipes (5). Further tests on pipe C showed that by moving the

transducer from the position shown in Figure 3 to 10.5m from end A, i.e. just before the start of the coating, the background noise level could be reduced. The results are shown in Figure 5.

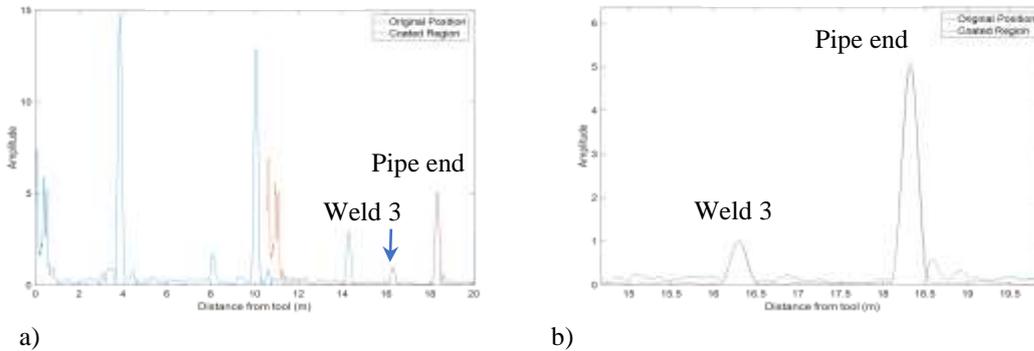


Figure 5. Effect of moving the *Teletest* transducer close to the start of the coating; original trace shown in blue, result after moving the transducer plotted in orange
a) Full length trace, may be compared with Figure 4a, b) Zoomed plot of the weld 3 region.

In Figure 5 the amplitudes have been normalised to the value of the response from weld 3, so that the effect on the local signal to noise ratio may be seen. There is at least a 6dB improvement in SNR around weld 3. This is believed to arise because, when the transducer is some distance away from the coated region, multiple path and slower-moving mode-converted signals from the low attenuation region may plot at the range on the A-scan that corresponds to the coated section. These signals are visible because a high gain is used to be able to observe the low amplitude responses from the coated region. In a wholly uncoated pipe a lower gain would be used and these responses would not be observed. When the transducer is moved closer to the start of the coating, as in Figure 5b, there is less opportunity for long path length signals from the uncoated region to be present in the data, so that the background signals observed in the coated region are reduced.

2.3 Post-processing

Despite the improvements described above, the signal quality on coated pipes remains poorer than for guided wave testing on bare pipes. It is therefore necessary to examine the possibilities of further improvement by the use of post-processing of the collected test data. A frequency domain method has been developed that enables virtually all the coherent noise on the baseline of the traces to be removed. Figure 6 shows the results from pipe C before and after a 9% cross-sectional area (CSA) slot defect had been cut in the pipe mid way between weld 3 and pipe end B. Figure 6a shows the whole length of the trace, as seen in Figures 4a and 5a.

The green trace in Figure 6a is the unprocessed data with a continuum of background signals after the introduction of the defect. The red trace shows the processed result. The real reflectors are preserved, even those which are multiple reflections from the high amplitude welds, and the background signals are removed. The response from the defect is clearly visible. Figure 6b shows a zoomed plot of the defect region. Several traces are plotted. The blue line is the unprocessed result without the defect. The green trace is the

unprocessed result with the defect present. Although the amplitude has increased, the presence of the defect cannot realistically be determined from the result.

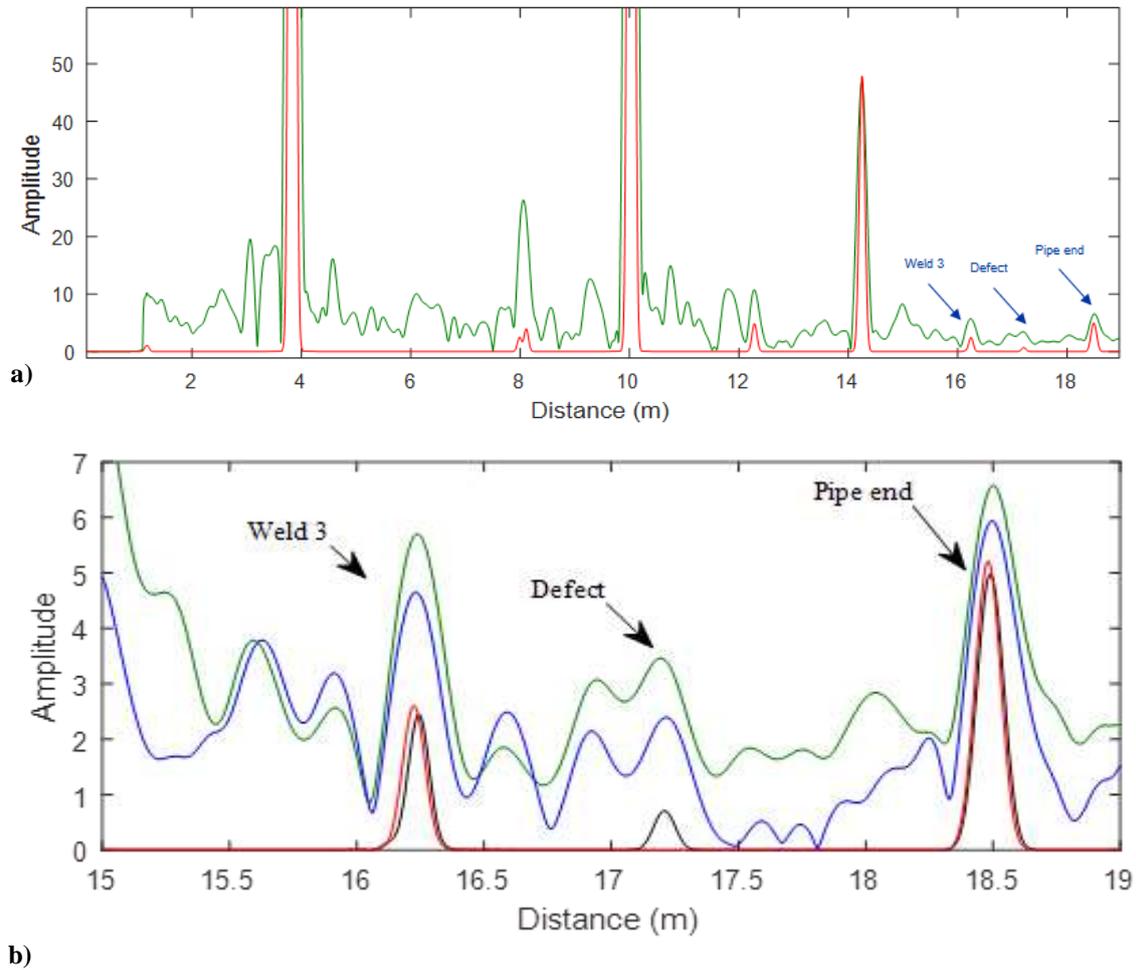


Figure 6. Results of post processing on the detection of a 9% CSA defect in pipe C.

a) Full length trace showing unprocessed data (green) and the processed result (red).

b) Zoomed plot of the defect region showing unprocessed data without defect (blue) and with the defect (green). Processed data are shown without defect (red) and with defect (black).

The post-processed results in Figure 6b are for the cases without the defect (red) and with the defect (black). The presence of the defect response at 17.2m may be clearly seen. The amplitude of the black response is 12dB down on the response from weld 3, which is in line with the expected response amplitudes from a weld and a defect of this size from the literature (4).

3. Conclusions

The attenuation rates for guided waves in pipes where viscoelastic coatings are present, and/or the pipes are buried in the ground, are sufficiently high to cause a major reduction in guided wave test capability. This is an intractable problem, but it has been shown that, by developing an understanding of the acoustic properties of the coating, procedural parameters may be selected to reduce the attenuation effects. Further, careful

attention to effects of the practical data gathering procedure can produce an additional increase in signal quality. It is nevertheless necessary to perform further processing of the received signals to provide comparable defect detection to that achieved on bare pipes and a frequency-based approach has been shown to be effective in limited trials.

Acknowledgements

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References

1. Ditri JJ, Rose JL. ‘Excitation of guided elastic wave modes in hollow cylinders by applied surface tractions’, *J Appl Phys* 1992, 72: 2589 - 2597.
2. Rose JL, Ditri JJ, Pilarski A, Rajana K, Carr FT. ‘A guided wave inspection technique for nuclear steam generator tubing’, *NDT E Int* 1994, 27: 307-330
3. Lowe MJS, Alleyne DN, Cawley P, ‘Defect detection in pipes using guided waves’, *Ultrasonics* 1998, 36: 147–154.
4. Demma A, Cawley P, Lowe MJS, Roosenbrand AG, Pavlakovic B, ‘The reflection of guided waves from notches in pipes: a guide for interpreting corrosion measurements’, *NDT&E Int* 2004, 37: 167-180.
5. W. Duan, R. Kirby, P. Mudge, T-H. Gan, ‘A one dimensional numerical approach for computing the eigenmodes of elastic waves in buried pipelines,’ *Journal of Sound and Vibration* 384 (2016): 177-193.
6. Duan W, Deere M, Mudge P, Kanfoud J, Gan T-H. ‘Modelling and measurement of guided wave propagation in Denso Tape coated pipes’, *First World Congress on Condition Monitoring*, London, UK, 2017