Testing of Buried Pipelines Using Guided Waves

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Introduction

The inspection requirements of pipes that have an operational history of many tens of years have lead to the adoption of new maintenance practices and safety standards. The solution currently considered as best maintenance practice is the direct assessment of 100% of the pipelines with the minimum possible economical impact. The use of RBI (Risk Based Inspection) methods and the introduction of new safety rules have also contributed to concentrate the inspection efforts onto the most critical parts of a given pipeline network. The cost of the inspection is in several cases a fraction of the cost for removal of the in service pipes and/or fittings. However when the pipe is buried the costs associated with NDT testing or substitution of the pipe substantially increase with respect to the same type of operation on an above ground exposed pipe. Buried pipelines can be tested using intelligent pigging methods. While this technology is generally accepted as providing excellent inspection data it is relatively expensive and it may also require significant operational disruption. As opposed to standard UT inspection methods the use of guided waves enable sections of piping to be tested from a single convenient to access location. Testing buried pipes can be performed by opening dig locations at appropriate positions and performing the test on the buried portion of pipe without direct access. This is particularly effective when testing crossings where the section of pipe under the road can be inspected from positions either side of the road.

The guided waves used in pipe testing applications are ultrasonic waves at low frequencies (generally below 100 kHz). Using conventional ultrasound techniques only the region of structure immediately close to the transducers can be tested (see Fig. 1(a)). Guided waves enable the screening of a relatively large region of structure from a single position (remotely located). These waves propagate along the structure instead of through the thickness as shown in Figure 1(b). The generation of these waves is obtained using a special transducer array. The contact between the pipe and the transducers is dry and mechanical or pneumatic applied force is used to ensure good coupling. After the transducer ring is positioned around the pipe the operator starts a rapid test which automatically sweeps several frequencies collecting data from either side of the ring at once (the system works in pulse-echo mode). The propagation of the ultrasonic signal depends on the conditions of the pipe under test. A range of 100 meters in either direction from the transducer ring position can be obtained when the pipe is in generally good condition and there is a low density of features (such as change of directions, drains, vents, valves, welds etc..). The range can be reduced to about 20 meters if the pipe is heavily corroded over its length. The system has been designed to detect defects that remove about 5% of the pipe wall cross sectional area although defect dimensions well below 5% (e.g. 1-2%) can be identified in pipes which are in generally good condition.

In this article we introduce the basics of guided waves for testing of pipes and the effect of contact with bituminous material or soil on the guided wave propagation. This is a new and challenging application area that has arisen from the demands of end clients. The new generation of guided wave equipment Wavemaker G3 has been specially developed to meet these needs. This article will discuss some examples which show the potential of using guided waves for testing buried pipes. The limits of this type of inspection are also discussed.

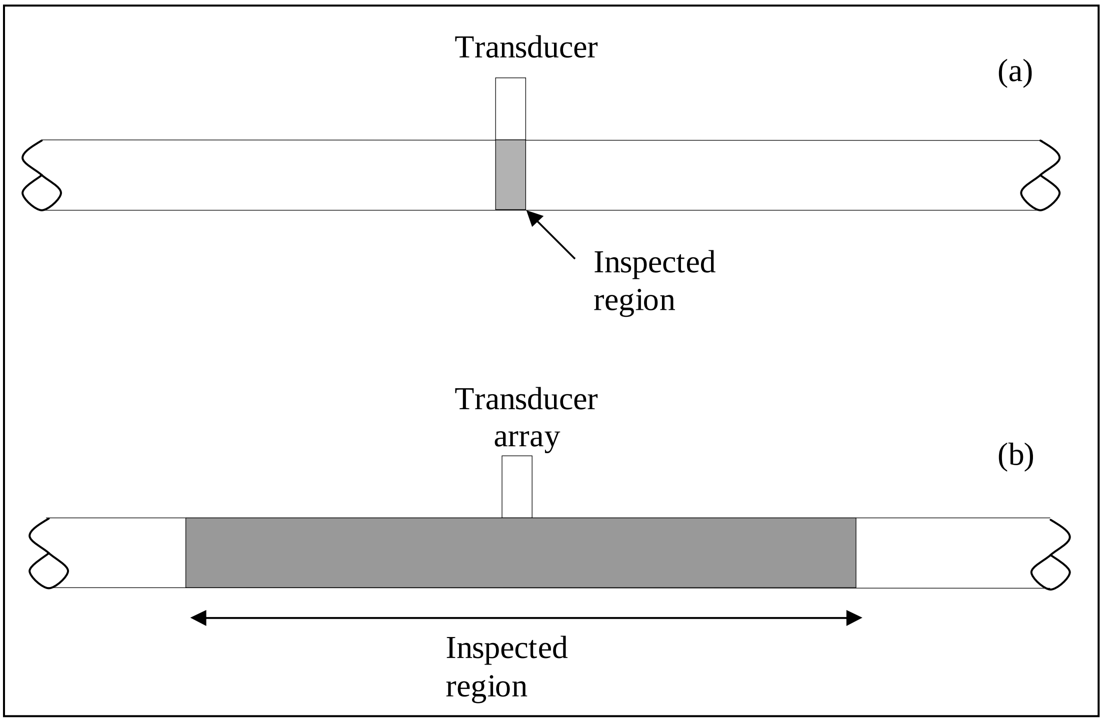

Figure 1 – Difference between traditional ultrasound techniques (a) and guided waves techniques.

Guided waves in cylindrical pipes

The propagation characteristics of guided waves depends on the geometry of the structure and the acoustic properties of the material. Figure 2 shows the dispersion curves for a 2 inch steel pipe in the frequency range between 0 and 100 kHz. These curves have been traced using the software Disperse [1] of Dr. B. Pavlakovic (Guided Ultrasonics Limited) and Dr. M. Lowe (Imperial College London). These curves are necessary for the use of the guided wave technology for testing pipes and in the case of the Wavemaker Pipe screening system the software Disperse is embedded in the WavePro Software. Each of the curve in Figure 2 represents one of the possible guided wave modes. Several modes exist in the range of frequency used for practical testing. However only a few modes are used in order to inspect the pipe. A simplification of the testing is imperative in a scenario as the one commonly seen in guided waves where the added complexity of using many modes could potentially compromise the practicality of using guided waves.

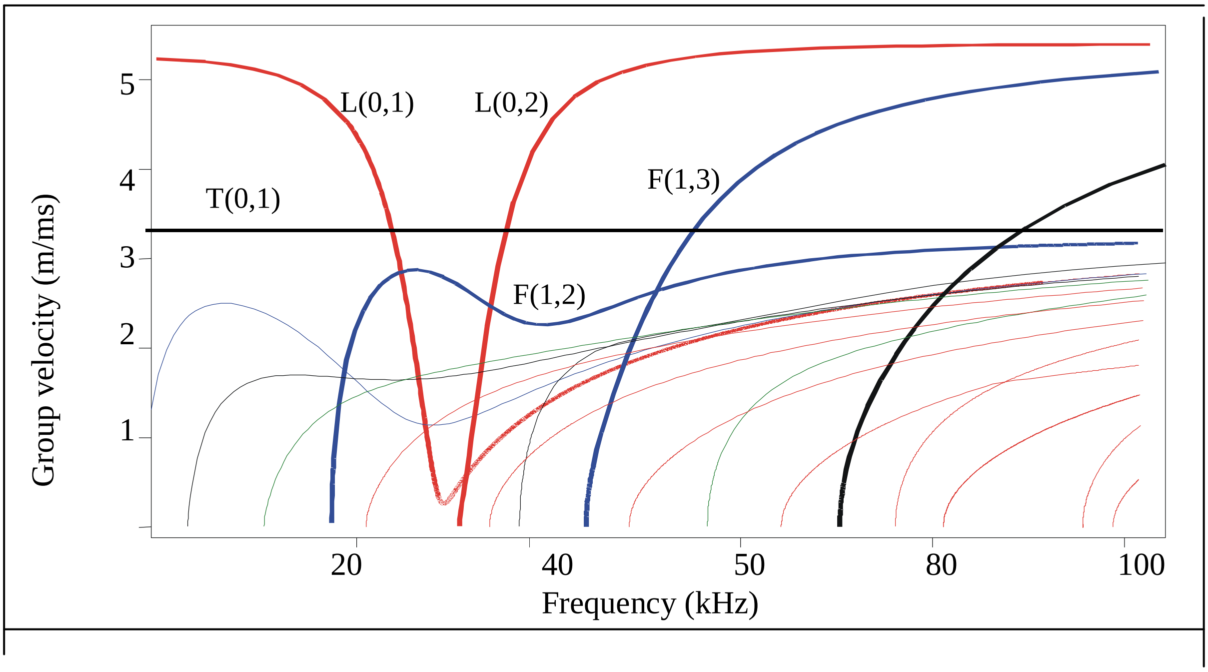

Figure 2 – Group velocity dispersion curves for a 2 inch steel pipe (4.5 mm wall thickness). The modes of interest are shown in bold and classified.

The choice of the mode to generate is of vital importance to the optimazation of the range and signal/noise of the guided wave test. It is best to use a mode in a non-dispersive region [2]. Therefore the torsional mode (T(0,1))is very attractive.

Single mode generation

In general all guided wave modes potentially existing at the frequency of excitation will be generated when a a single transducer is used. The generation of a single mode simplifies the practical application of the guided wave method (T(0,1) is the mode generally preferred but other solutions are also available). The technique developed by the members of Guided Ultrasonics uses piezoelectric transducers in order to generate the desired modes.

The signal excitation, data collection and postprocessing are obtained by using a lightweight and compact system composed of a laptop, a Wavemaker and a transducer ring as shown in figure 4.

Mode reflection and mode conversion

In a pipeline there are several features which interrupt the geometrical continuity of the cylindrical tube, for example welds, flanges, support and curves. All those features cause a reflection of the guided wave which is recorded by the system. Moreover the pipes can have defects with different distribution (generalized or localised) and orientation (circumferential, axial and through the thickness). Lowe et al. [3] found a method of identification of defects using the characteristics of reflection and mode conversion. A symmetric feature such as a weld or a flange causes only a reflection of the generated mode (which in the case of the Wavemaker is in general a pure torsional mode or a pure longitudinal mode). This is caused by the fact that both the geometry of the feature and the characteristics of the mode are axisymmetric. When the discontinuity is non-axi-symmetric (e.g drains, curves, defects etc..) there will be not only a reflection but also a mode conversion of the signal. The mode conversion characteristics have been studied and in the case of the torsional mode T(0,1) it has been demonstrated that this tends to convert to the F(1,2) mode [4].

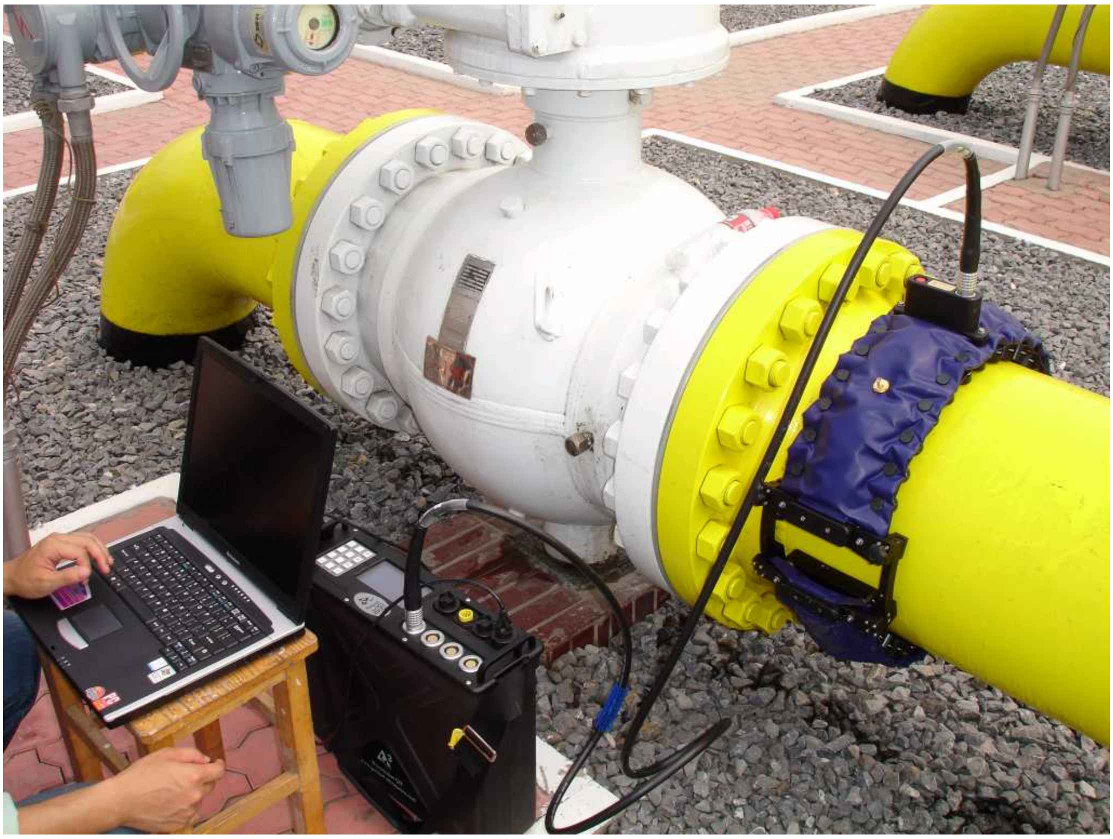

Figure 4. Wavemaker G3 kit used in site-test.

Defect sensitivity

The guided waves used for testing pipes are sensitive to changes in the cross section of the pipe. The reflection characteristics of guided waves are different from the reflection rules of bulk waves. Guided waves enable the detection of defects much smaller than the wavelength. The results of sensitivity study of guided waves has been published in previous publications [3,4,5].

Effect of bituminous coatings

The effect of bituminous coatings has been reported in previous studies on the prediction of the lossy behavior of bilayers [6]. The most known effect of bituminous type coatings is to cause a strong attenuation of the ultrasonic guided wave. This type of coating is therefore responsible for a reduction of the range of propagation of the signal. In this paper we show some examples of bitumen coated pipes successfully tested in spite of the strong attenuation of the ultrasonic signal due to the coating.

Effect of contact with soil

Contact with soil causes an effect of attenuation of the signal. Moreover the guided waves in pipes in soil behave differently than in the case of a bare pipe. Some theoretical studies on this specific matter are being carried out [7].

Screening of buried pipes using guided waves

Buried pipes are among the most complex applications of the guided wave technology. All alternative solutions to guided wave testing have a strong economical impact. Intelligent pigging method has high associated costs and it may cause disruption of the production. The direct assessment is very costly especially in locations were the digging site would disrupt the passage (e.g. road crossings or rail crossings). In several cases the costs related with the direct assessment with standard technology are so high to justify a substitution of the line without performing the tests. Guided waves enable inspection of buried pipes from an exposed section. The result of the test is the screening of a relatively long section of pipe from a remote location. This is especially useful when testing road crossings and rail crossings where the portion of pipe to be screen is limited to a few meters and the pipe can be accessed from both sides of the crossings.

The limitations of the test on the buried section of pipe are related to the presence of material which causes strong attenuation of the guided wave (such as thick bitumen coating), the presence of complex geometries and the contact with the soil.

The third generation of guided wave equipment (G3) enables better performance in terms of range of test when the limiting factor is the presence of attenuative materials.

In the buried pipe testing using guided waves the effect of contact with the soil can dramatically increase the difficulty of the analysis. For this reason it is recommended that only experienced operators are used to test buried pipes.

Figure 5 shows a buried pipe at the time of test with the Wavemaker G3. This test was performed from a location close to a valve. On the right of the transducers ring it is possible to see the flange which is the end of test in the positive direction. The region of pipe on the left of the ring (in Figure 5) was covered with bituminous type of coaating and buried.

The result of this inspection is shown in Figure 6. In this case about 30 meters of pipe could be tested from a single location. Two weld reflections are clearly visible on the buried section of pipe. A third weld was located at about 30 meters (100 feet) from the ring location; the identification of this third weld requires high level of experience. In the inspected section of pipe there are no echoes above the 5% estimated cross section which could be associated with the presence of corrosion.

On the basis of this result the final client classified the line as being in good conditions. This was done on the basis of the screening of 100% of the volume on a portion of 30 meters of pipe. The maintenance program based on the initial information from the guided wave data enables to concentrate the follow-up work on the pipes which need close attention due to their critical condition.

Figure 5. Wavemaker G3 in action. Test on a buried section of pipe from an accessible remote location.

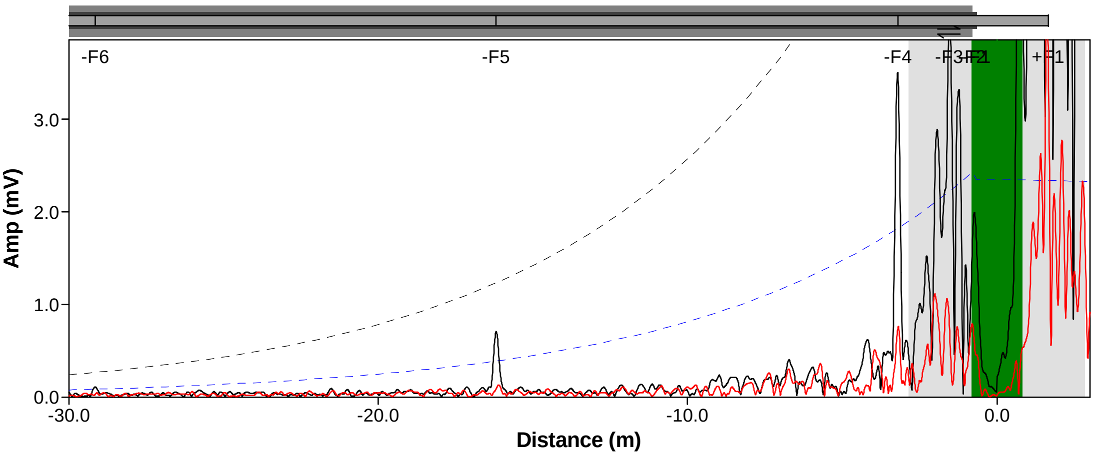

Figure 6. Wavemaker G3 result for buried pipe in Figure 5. Thirty meters (100 feet) of buried pipe were tested from a single location.

Another buried pipe is shown on Figure 7. The pipe under examination is a length of 8inch buried pipe. A small dig site enabled local access to the pipe; a short section (about 0.5m) of bituminous type of coating was removed in order to ensure good coupling between the rings and the pipe.

The result of the inspection on this pipe is shown on Figure 8. The range of the test in this case is about 25 meters (75 feet) on each side of the ring locations. No corrosion areas are predicted to be above a 10% change in pipe wall cross section. However, the pipe has a number of localized indications that are at about the 5% ECL level. The areas with the larger indications have been identified with blue colour. The average attenuation at this location was about -2dB/m. It is worthwhile noting that some of the most identifiable areas are near or adjacent to welds.

At a different location on the same line some corrosion patches were noted on one of the dig sites (see Figure 9). This confirms that the line is characterized by the presence of corrosion patches consistent with the defects identified in the result presented in Figure 8.

On the basis of this result the final client was suggested to program the periodical re-test of this pipe.

Figure 7. Exposed section of 8 inch pipe. A small portion of coating was removed (0.5m length) in order to couple the ring onto the pipe.

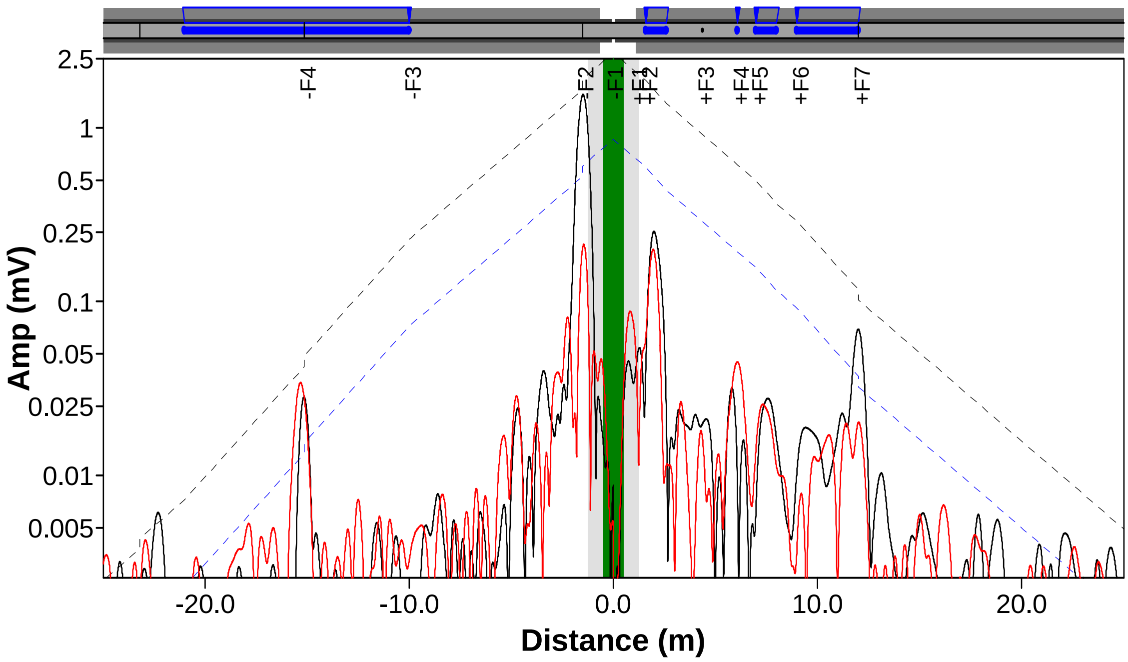

Figure 8. Wavemaker G3 result for buried pipe in Figure 7 (Amplitude is shown in logarithmic scale). About 25 meters (75 feet) of buried pipe on each side of the ring were tested from a single ring location. Several areas of concern have been identified.

Figure 9. Corrosion patch found at exposed location about 30 meters away from the exposed location shown on Figure 7.

Limitations

The range of test on a buried pipe is variable and depends on the conditions of pipe, coating and soil. Therefore not in all cases it is possible to achieve a range above 20 metres as seen in the examples shown in this paper. G3 technology has improved the performance for the testing of buried pipes but the limiting factors can sometimes reduce the range of the inspection to only about 5 metres either side of the ring.

Conclusions

The guided wave technique enables rapid screening of long lengths of pipelines for the detection of corrosion and other types of defect. The use of this technology for the inspection of buried lines enables a direct screening assessment of 100% of the line for the diagnostic length of the test. Tens of meters of buried pipe can generally be tested from a single location. The implementation of the guided wave technique can substantially reduce the economical impact of the inspection and maintenance program if compared with alternative techniques. The inspection of buried pipes is an advanced type of application for guided wave testing which requires that the analysis of data is performed by experienced operators.

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