Design of pipelines for Guided Wave testing (GWT)
Mark J. EVANS 1, Thomas K. VOGT 1
1 Guided Ultrasonics Ltd, London, UK; Phone: +44 2082329105; e-mail: mark@guided-ultrasonics.com

Abstract
The concept of design for inspection, whereby a component or structural element is designed with 'inspectability' built in, is common practice in the nuclear and aerospace industries but is not so prevalent in the petrochemical industry.

The design of a pipeline for inspection using GWT requires knowledge of the capabilities and limitations of the GWT method and an understanding of the physical characteristics which affect the performance such as the range and sensitivity of the test. This paper will discuss these physical characteristics, such as access to the pipeline, geometry of the pipeline and types of coatings. Practical examples and potential solutions are also presented for some specific example case studies.

Effective inspection reduces unplanned maintenance, reduces the risk of failure and ultimately increases the working life of the pipeline. By designing pipeline appropriately the effectiveness and therefore the benefits of GWT can be assured.

Keywords: In-service, power plant, chemical and petrochemical, guided waves (lamb waves), GWT, pipe, inspection, design

1 Introduction
The importance of effective inspection is becoming more widely acknowledged due to a variety of factors [1], such as:

- Regulatory pressures for more frequent and thorough inspections;
- Potential cost of fines and penalties if failure occurs;
- Requirement to extend the working life of assets, or change their operating conditions.

GWT is being used routinely worldwide for the in-service inspection for a wide variety of pipe inspection applications and conditions, from offshore and marine environments to pipes laying in the desert sand or Alaskan tundra. Many of these lines are more than 30 years old and may never have been thoroughly inspected before due to a lack of any practical inspection method being available.

The effectiveness of GWT is dramatically affected by the physical characteristics of the pipeline, such as the pipe coating material and the physical geometric features. Clearly, for existing pipelines, these physical characteristics were chosen at the time of construction and cannot be modified: The time and cost required to carry out GWT inspection is therefore strongly dependent on these historic choices. A great deal of effort has gone into the writing of procedures and the development of GWT equipment to provide inspection solutions for existing pipelines, however, very little emphasis has been placed on advising pipeline designers and constructors on how to make new pipelines which can be inspected more effectively.

A major consideration for new pipelines is to reduce risk, inspection effort and cost by designing and constructing the line with specific inspection methods in mind. There are clearly many design parameters which may influence the effectiveness of guided wave inspection. The most important of these parameters, which will be discussed in detail in this paper, are:
• The ability to gain access to appropriate test locations;
• The type of coating and how this affects the setup and performance of the test;
• The geometry of the pipeline and pipe fittings such as flanges, elbows and tees;
• The pipe supports and other attachments.

Before discussing the physical characteristics of the pipeline which affect GWT inspections it is first necessary to give a brief summary of the state-of-the-art regarding the GWT method.

2 Guided Wave Testing

2.1 Introduction

Guided wave testing is a non-destructive testing method for finding corrosion in pipe-work. It uses mechanical waves that propagate along the pipe in the axial direction. The GWT method is now widely accepted worldwide and is covered by several international standards, for example [2].

In contrast to ultrasonic testing (UT), where only the area underneath or in the direct vicinity of the transducer is inspected, GWT testing allows the entire pipe wall to be screened from a single transducer position. The diagnostic range of the test depends on a number of parameters, but in the applications considered here is generally of the order of tens of metres in both directions. This makes GWT an ideal tool for screening long lengths of pipes for defects and locating them for prove-up inspection. Prove-up, for example with UT, is an integral part of the inspection procedure [2].

2.2 Typical Performance

The following sections briefly describe the current performance and capabilities of the Wavemaker® system, a more general discussion of GWT can be found in [3].

2.2.1 Range and test duration

The achievable test range for GWT depends strongly on the pipe condition and the presence of viscous, thick coatings, such as bitumen wraps. A Typical range which can be achieved on insulated pipework is 70m (35m in each direction from the transducer ring). Data collection for this range using the Wavemaker system takes between 3 and 5 minutes, depending on the collections settings which have been used.

2.2.2 A-Scan and C-Scan display

Once the data has been collected the Wavemaker® system provides several methods for displaying the processed result. The most commonly used are:

• A-Scan display: A distance versus amplitude graphical display in which the amplitude of reflected signals is plotted against the distance from the ring (positive and negative directions), see lower section of Figure 1.

• C-Scan display: The reflected amplitude is plotted on a colour scale versus distance from the ring and circumferential orientation (clock position), see upper section of Figure 1.
Analysis of the data requires no additional data collections and so can be carried out after removal of the transducer ring from the pipe.

![Normalized amplitude range (weld DAC is 0 dB)](image)

Figure 1 Data display types, A-Scan display (lower) and C-Scan display (upper).

2.2.3 **Sensitivity and POD**

The sensitivity of GWT equipment is quoted in terms of the minimum detectable percentage cross sectional area change of the pipe wall (CSC). The sensitivity is affected by the general pipe condition but for Wavemaker® equipment is typically quoted as between 2% and 5% CSC. A major incentive for using GWT is the high probability of detection (POD) for defects [3] due to the large coverage which can be achieved.

3 **Important factors for guided wave testing.**

3.1 **Access**

Access to the entire pipe circumference is required for a length of between 0.5m and 1m at each GWT testing location. The exact location and spacing of the GWT test location depends on test range, pipe features and pipe geometry. Generally the testing locations can be between 20m and 100m apart if 100% coverage of the pipeline is required.

Providing access by removing insulation, erecting scaffolding or digging inspection pits can be the most expensive part of any inspection process. These costs can be minimized by careful planning. Two example applications are given below:

1. **Pipes in overhead pipe-racks.** Access to the pipe can be easily provided at the stanchions by means of fixed ladders and walkways. If these access points are provide frequently enough along the pipe length, all routine GWT inspection can be carried out without the use of scaffolding or portable lifts. Additionally, if the lines are insulated, removable 1m sections of insulation could be provided which can be used
by the GWT inspector to gain access to the pipe surface for the inspection without requiring additional operations or permits.

2. **Buried road-crossings.** If frequent inspection is required, for example every 3 years or less, it may be economically viable to provide a permanent inspection pit, rather than to re-excavate the test location at every inspection cycle. Alternatively, a permanent GWT sensor can be attached to the pipe and buried, allowing retesting without excavations. The gPIMS® sensor manufactured by Guided Ultrasonics Ltd’s is suitable for just this purpose [3].

Once access to the test location has been achieved preparation of the pipe surface may be required before GWT can be carried out. The most important factor for this stage of the process is the coating system which is present on the pipeline

### 3.2 Pipe Coatings

The purpose of pipe coatings are to protect the pipe surface from a variety of potential chemical and mechanical damage mechanisms such as atmospheric corrosion or mechanical abrasion. Unfortunately, coatings often have the unintended consequence of making inspection of the pipe (using UT, VT or GWT) more difficult, or in some cases, commercially unviable. In many cases there is a choice of several coating systems which can be used to provide the necessary protection. Optimal choice of coating will provide the necessary protection to the pipe without rendering it untestable.

The pipe coating affects the GWT performance to two important ways

1. **Coupling of acoustic energy into the pipe:** As a general rule coatings which are non-viscous, well bonded and less than 1mm thick do not have to be removed for GWT to be carried out: This includes most paint, FBE and metallic coatings as well as some polyethylene coatings.

2. **Attenuation of the acoustic energy along the pipe length:** The attenuation is the single largest factor affecting the productivity of GWT inspection. Again, non-viscous coatings are optimal for GWT as they exhibit the lowest attenuation and therefore the longest diagnostic test ranges. In optimal conditions the test range can be over 200m in each direction, however, for high attenuation coatings it can be less than 2m. So careful selection of materials is crucial.

It is important to emphasise that coatings do not only affect the inspection performance of GWT. Conventional UT inspection techniques, due to their higher frequency of operation, are in many cases more affected by coatings. UT measurements are part of the standard GWT procedure and so it is often necessary to remove areas of coating to allow these UT measurements to be carried out, even when the GWT could be carried out without any coating removal.

The example in Figure 2 shows an excavated section of buried pipe. The pipe coating is FBE which is overwrapped with a plastic mesh, or ‘rock guard’, which provides mechanical protection to the coating (a short section of this ‘rock guard’ can be seen at the soil entrance, the remainder has been cut away temporarily during the inspection). This coating system has major advantages over more conventional bitumen wrapping. Pipe inspection can be carried out using both GWT and conventional UT techniques without removing the FBE coating.
The attenuation of the guided waves is relatively low giving good diagnostic range and sensitivity. Figure 3 shows the GWT result from this pipe section in which the diagnostic range was close to 25m and the sensitivity was 1.8% CSC. Typical test range for a bitumen coated pipe would be around 10m with a sensitivity of around 3% CSC.

The photograph and GWT result show that the ‘rock guard’ has protected the pipe coating from the ungraded backfill and therefore the pipe and coating condition are very good.

For unburied lines, such as those in refineries or chemical plants, typical coatings exhibit low attenuation and so do not limit the performance of GWT. However, the geometry of the pipelines may be complex and how this complexity affects the GWT is an important topic.

### 3.3 Pipe Geometry

Guided waves can be described as structural waves as their properties (such as velocity and mode shape) depend on the geometry of the structure along which they are guided [3]. Any changes to the geometry of the structure will cause reflections and distortions of the guided waves. The ideal pipe geometry for GWT is therefore continuous straight sections, such as
you find in transmission lines or pipe-racks. Many pipelines have pipe fittings such as flanges and elbows which will reduce the range and sensitivity of the test, the effect of these features can be summarised as follows:

1. **Flanges.** A flange represents the end of the diagnostic range for GWT, all of the signal is reflected. Therefore for pipelines which are made up of flanged sections, GWT can only be used to individually test each section.

2. **Elbows.** Elbow fittings are common, especially in process pipework, and they can cause severe distortion of the guided waves. Where the elbow has a small radius of curvature (for example 1D), the distortion of the signal is often significant enough to necessitate the end of the GWT test. Selection of larger radius, more gradual bends, significantly improves the GWT performance such that the bend has little or no distortion effect on the GWT performance.

The picture in Figure 4 shows how this knowledge can be applied in practice for the design of jump-overs and sleeved road crossings.

![Figure 4](image-url)

Figure 4. Jump-overs and road-crossings can be designed to maximise the performance of GWT by avoiding the use of small radius-of-curvature elbows.

In the example show in Figure 4 the bends chosen for the jump overs are large radius-of-curvature which cause little or no distortion of the guided wave signal which allows the pipelines to be inspected from test locations at ground level, without the use of scaffolding or access cranes. Additionally, the pipes which cross beneath the road are ideally designed for GWT being straight and protected by an FBE coating within a sleeve.

### 3.4 Pipe Supports

In addition to pipe fittings, pipe supports also represent a change to the geometry of the pipeline and therefore can cause reflection and distortion of the guided waves. There are several types of supports which can be divided into three main categories:

1. **Welded supports.** These are permanently attached to the pipe by way of welded joints. There are a large variety of types and geometries of welded supports as there appears to be no recognised standard for their use. Welded supports cause the largest
reflections and distortions and can, for small diameter pipes, reduce the diagnostic range to less than 15m [6].

2. **Clamped supports.** These are non-permanent attachments to the pipe by way of bolts or straps. Again, a large variety of types and geometries exist and no common standard is followed governing their usage.

3. **Simple supports.** These supports do not have any attachment, the pipe simply rests on a surface, this type of support is also known as a point-of-contact support.

GWT performance is best when supports are soft-faced using materials such as plastic, rubber or wood. The guided wave signal is not reflected or distorted by supports of this type and sensitivity and test range are maximised.

An additional benefit to using soft-faced supports is that the support does not damage the pipe coating [8]. Where the support has a hard material in contact with the pipe it is common to find accelerated corrosion at the support locations due to the coating damage caused by the wearing action of the support, see Figure 7.
onset of corrosion.

For insulated pipelines it is common to use welded supports which protrude through the protective cladding on the insulation. These supports can allow moisture to penetrate though the insulation and are therefore known to be sites of accelerated corrosion, see Figure 8. Additionally they cause a reduction in the performance of GWT.

An alternative design of support for insulated pipelines has the support external to the insulation instead of being in direct contact with the pipe surface, an example is show in Figure 9. This support type has several advantages:

1. There is no break in the protective cladding which reduces the risk of water ingress and corrosion at the supports.
2. There is reduced heat loss from the pipe into the support and surrounding environment.
3. The supports have no detrimental effect on the performance of GWT because there is no direct metal to metal contact with the pipe.

Figure 8. Example of corrosion at welded support after insulation has been removed. Figure 9. Example of thermally insulated supports.

4 Conclusions

This paper provides recommendations for optimal pipeline design in order to maximise the performance of GWT. The design parameters discussed are, access, coatings, geometry and supports but there are other considerations such as linings and other pipe attachments.

Poor pipeline design can prove to be very expensive in the medium to long term as inspection and maintenance can become prohibitively expensive. Good design not only reduces the likelihood of corrosion but, if the design also enables effective inspection to be carried out cost effectively, allows the working life of the pipeline to be extended indefinitely (provided that the inspection can verify that the pipeline condition is within acceptable limits).
Ideally, specialists in the relevant NDT methods should be involved at the design stage to advise on suitable design parameters. The results presented in this paper demonstrate that if suitable decisions are made when a pipeline is being designed, the effectiveness of future inspection of the pipe can be maximized.

Acknowledgments
The authors would like to thank Bradley Elfstrom of Mistras for providing the case study material for the example in Figure 2 and Figure 3.

References