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A new methodology for verifying the structural integrity of metallic tubular structures (e.g. poles for public lighting, piping etc.)

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Introduction

The control of the state, from the corrosion point of view, of metallic structures (pipes, poles etc.) has a considerable importance for the safety of people and for the efficiency of the installation. This is more than ever important due the age of the equipment so far installed and the growing requirements for the reliability and safety of this type of structures.

This kind of control is particularly complex however, because of the unpredictability with which faults and corrosive phenomena occur. In particular, external agents can often interfere by changing locally the corrosion rate, thus making it difficult to assess how the real state of structural integrity might evolve and therefore to decide whether to replace or revise them over time.

The methodology was developed specifically to complement traditional methods based on the measurements of corrosion rate and corrosion potential, electrical attenuation and gradients with the recent measurement techniques using ultrasonic guided waves. These diagnostic tests are placed in the context of a complex procedure and flexible structural algorithm that combines the mechanical with the corrosion aspects through an innovative Mechanical/Corrosion Diagram.

Both the technique and the relevant methodology can easily be applied to tubular structures such as poles, pipelines, especially when they are exposed above ground, (piping in Compressor or Pumping Stations, petro–chemical plants and similar).

1 – Guided waves in cylindrical pipes

The Guided Waves technique used for pipe testing applications are ultrasonic waves at low frequencies (generally below 100 kHz). When using the conventional ultrasonic technique, only the region of structure immediately close to the transducers can be tested (see Figure 1(a)). Ultrasonic Guided waves enable the screening of a relatively large region of structure from a single remote position. These waves propagate along the structure instead of through the thickness as shown in Figure 1(b). The generation of these waves is obtained by using special transducers array. The contact between the pipe and the transducers is of dry type and mechanical, or a pneumatic applied force is used to ensure a good coupling. After the transducers ring has been placed around the pipe, the operator starts a quick 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 signals depends on the conditions of the pipe under test.

A range of 100 meters in either directions from the transducers ring position can be efficiently scanned when a bare pipe, being in overall good conditions, has a low number of features (such as change of directions, drains, vents, valves, welds etc..). This useful range is reduced to less than 20 meters if the pipe is bare and heavily corroded over its length. The system has been designed to detect defects having metal loss of about 5% of the pipe wall cross sectional area, although smaller defect much below 5% (e.g. 1-2%) can be identified in pipes which are in generally good conditions.

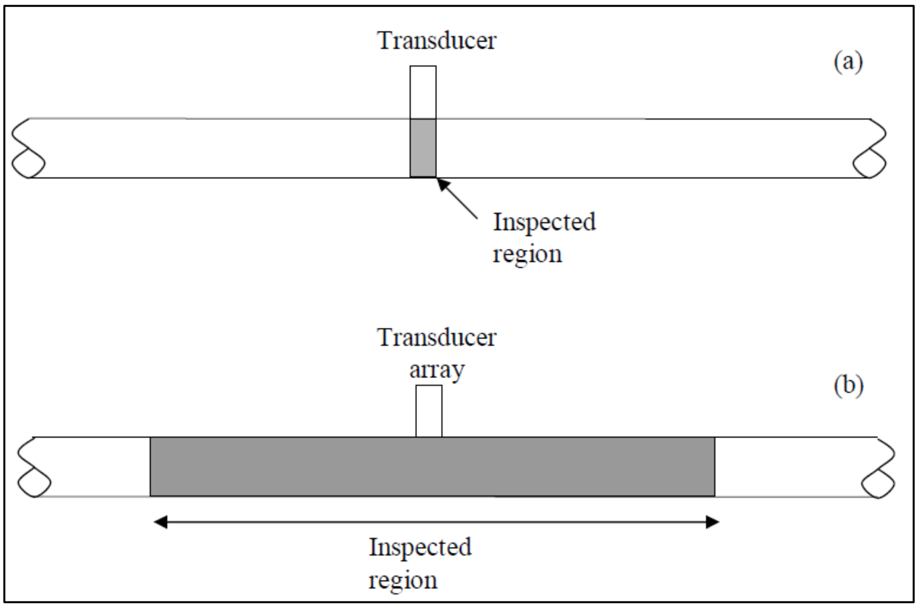


Figure 1 – Difference between traditional Ultrasonic techniques (a) and Ultrasonic Guided Waves techniques (b).

2 – Propagation mode, characteristics of reflection of Ultrasonic Guided Waves

2.1. Propagation Mode

An ultrasonic guided wave can propagate in tubular structures in different modes; each mode is characterized by its typical oscillation along the pipe (torsional, longitudinal, flexural) and by its typical frequency/velocity relationship. This aspect is very important for the identification of defects and the velocity independent from frequency is generally preferred (non dispersive mode)

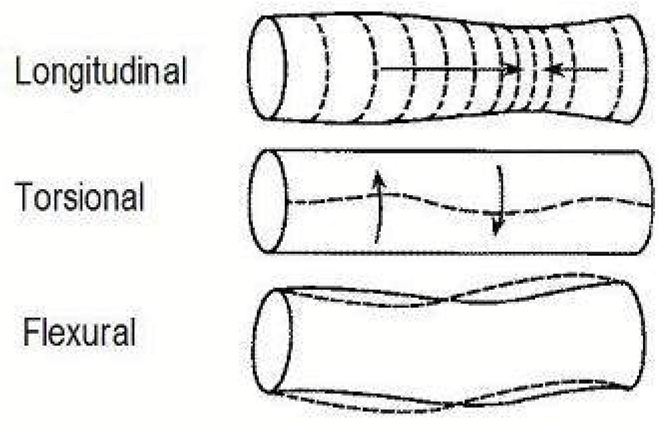


Figure 2 – Various Modes of Propagation of Ultrasonic Guided Waves.

2.2. Reflection characteristics of Ultrasonic Guided Waves

Ultrasonic waves propagate along the tubular structure and are reflected every time a cross sectional change (weld, defect etc) or a change of material stiffness change (welded supports etc.) occur.

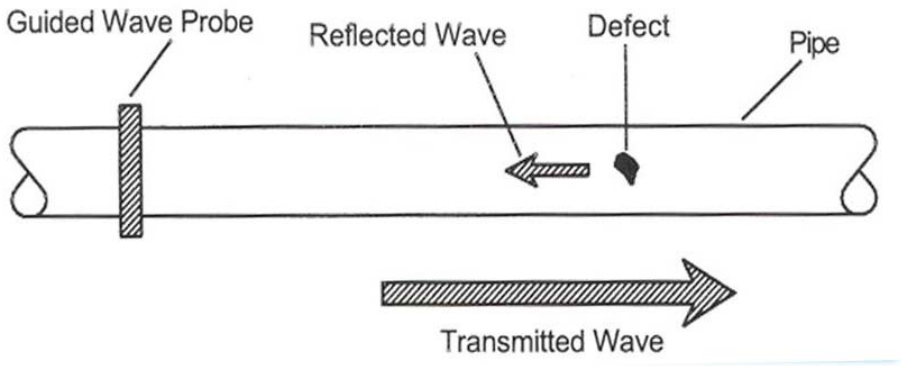


Figure 3 – Propagation of Ultrasonic Guided Waves and Reflection from defects

2.3. Propagation of the Ultrasonic Guided Waves

The propagation characteristics of guided waves depend on the geometry of the structure and from the acoustic properties of the material. Figure 4 shows the dispersion curves for a 2 inch steel pipe in the frequency range between 0 and 100 kHz. These curves are necessary when using the Ultrasonic Guided Waves technology for testing pipes and in the case of the Pipe screening system. Each of the curve in Figure 4 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.

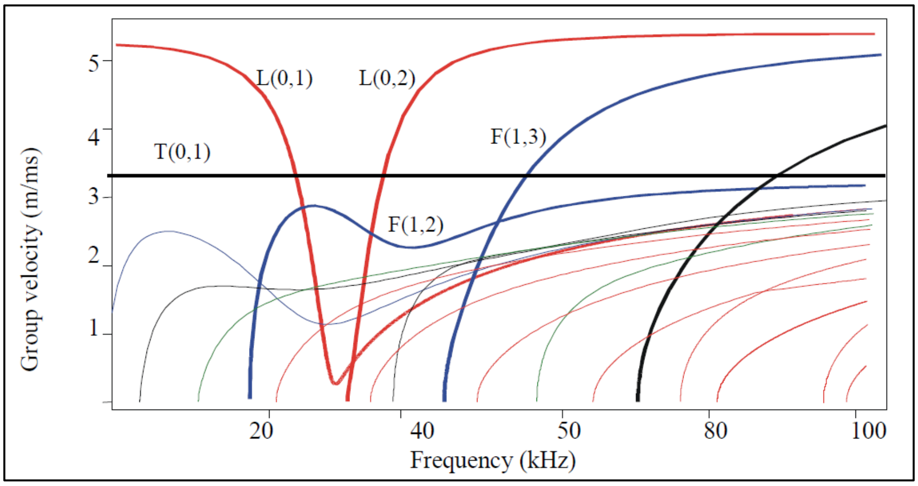


Figure 4 – Group velocity dispersion curves for a 2 inch steel pipe (4.5 mm wall thickness). The modes of interest are shown in bold and classified.

The choice of the mode to generate the waves is of vital importance in order to optimize the range of the signal/noise of the test. It is best to use a mode in a non-dispersive region [2]. Therefore the torsional mode (T(0,1)) is the best one.

3 – Examples of Pipe Testing

In general all guided wave modes potentially existing at the frequency of excitation will be generated when 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: piezoelectric transducers can be easily used to generate the desired modes.

The signal excitation, data collection and post-processing are obtained by using a lightweight and compact computerized system kit as the one shown in figure 4.

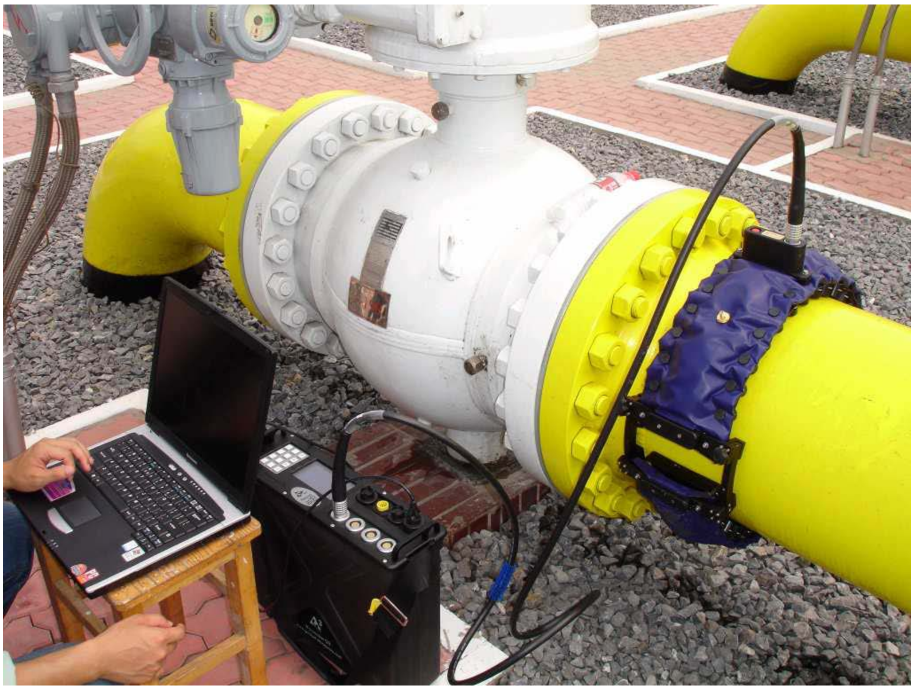


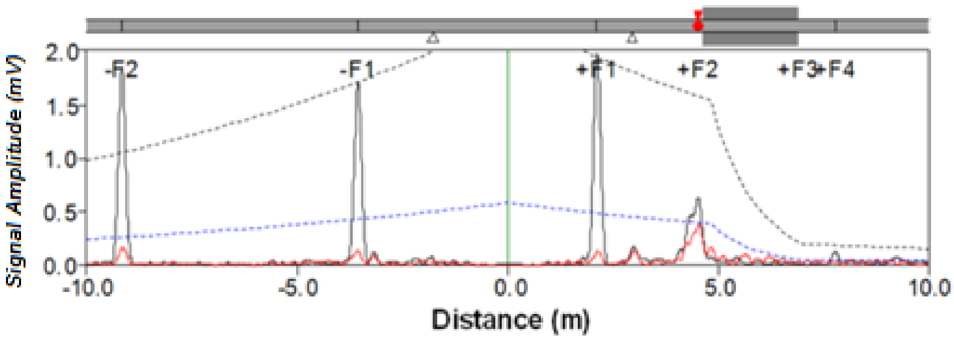
Figure 5. Computerized system kit used in site-tests.

In a pipeline there are several features which break the geometrical continuity and uniformity of the cylindrical tube such as welds, flanges, supports and curves. All these features cause a reflection of the guided wave which is recorded by the system. Moreover the pipes can show defects having different area distribution (e.g. generalized or localized corrosion) and orientation (circumferential, axial and through the thickness). Lowe et al. [3] found a method to identify the defects according to their characteristics of reflection and their mode conversion. A symmetric feature such as a weld or a flange causes only a reflection of the generated mode (which in this case 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 symmetric to the longitudinal axis. When the discontinuity is not symmetric to the axis of the pipe (e.g. drains, curves, corrosion 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.

The guided waves used for testing pipes are sensitive to changes in the cross section of the pipe. The reflection characteristics of the guided waves are different from the reflection

rules of bulk waves. Guided waves enable the detection of defect dimensions much smaller than the wavelength The minimum target of Guided Waves tests is 5% of section loss defect but, in ideal condition it can be much more sensitive.
The results of sensitivity study of guided waves have been published in previous publications [3,4,5].
In Figure 6 (a) the welds (-F2 -F1 +F1 +F4) are clearly identified even after the wall crossing where a severe defect is visible (F2). In Figure 6(b) the bends (-F2 +F2 +F3) and severe corrosion under support (-F1 +F1) are clearly identified

Case a): Pipe near a wall crossing



Case b): Pipe with multiple bends sustained by metallic supports

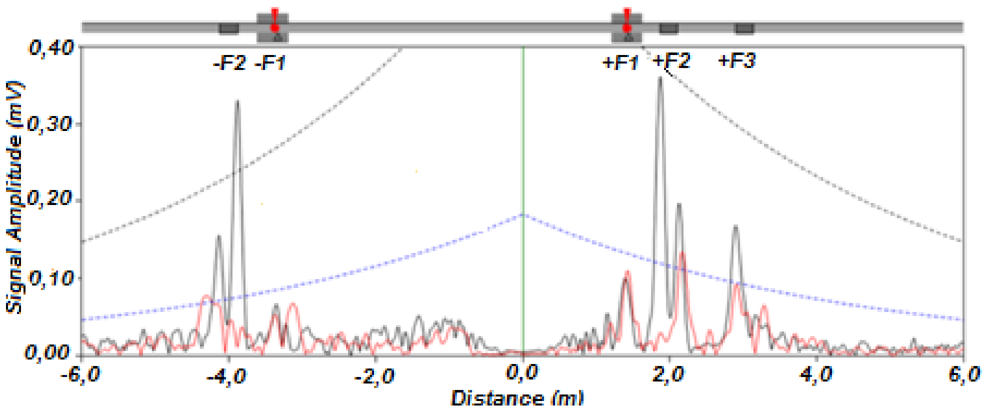


Figure 6 – Test results near a wall crossing (a) with a defect localized (+F1) and
on a multiple bends pipe (b) (-F2, +F2,+F3) with corrosion under the supports (-F1; +F1).

4 – Influence of coatings and burial of pipes

The effect of soil and/or the presence of bituminous coatings has been reported in previous studies on the prediction of the lossy behavior of bi-layers (pipe and coating) [6].
The most known effect of bituminous coatings is to cause a strong attenuation of the Ultrasonic Guided Waves. This type of coating is therefore responsible for a reduction of the range of propagation of the signal. Moreover the guided waves of 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]. Buried pipes are among the most complex applications of the Ultrasonic Guided Wave technology. Nevertheless, any alternative solution to guided wave testing has a strong economical impact. The Intelligent Pigging method has high associated costs and it may cause interruption of the production. The direct assessment

by digging is very expensive especially in those locations were the digging would destroy the right of way (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.
On the other side, Ultrasonic Guided Waves enable inspection of buried pipes from an exposed section. These tests can scan a relatively long section of pipe from a relatively remote location. This methodology can be especially useful when testing road crossings or rail crossings where the portion of pipe to be scanned is limited to a few meters and the pipe can be accessed from both sides of the crossing. The recent generation of Ultrasonic Guided Waves Equipment enables better performances in terms of range of test when the limiting factor is the presence of attenuative materials.
In buried pipelines the presence of soil can dramatically reduce the capability and increase the difficulty of the analysis. For this reason it is highly recommended that only experienced operators are employed to test buried pipelines.
A buried 8" pipeline is shown in Figure 7(a). A small dig enabled the local access to the pipe; a short section (about 0.5 m) of bituminous coating was removed in order to ensure a good coupling between the test probe 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 both sides of the probe location. No corrosion areas are predicted to be above 10% of the pipe wall cross section. However, the pipe has a number of localized features that are at about the 5%of ECL (Estimated Cross-Section Loss) level. The areas with the larger indications have been identified with blue color. The average attenuation at this location was about - 2dB/m. It is worth 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 in one of the dig sites (see Figure 7b). This confirmed that the line was characterized by the presence of corrosion patches consistent with the defects identified in the results shown in Figure 8.


(a)


(b)

Figure 7.
(a) Exposed section of an 8 inch pipeline. A small portion of coating was removed (0.5m length) in order to couple the probe ring with the pipe;
(b) Corrosion patch found at exposed location about 30 meters away from the location shown in Figure 7a

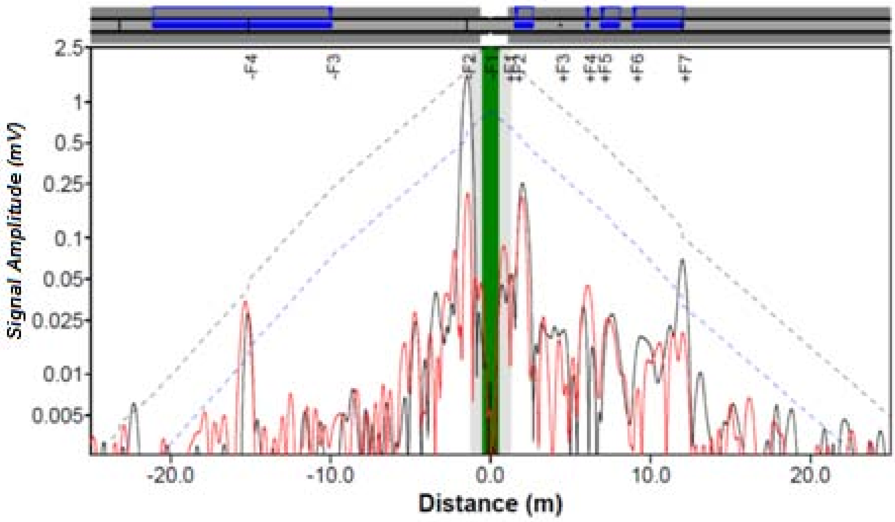


Figure 8. - Guided Waves result for buried pipe in Figure 7 (Amplitude is shown in logarithmic scale). About 25 meters of buried pipe on each side of the ring were tested from a single ring location. Several areas of concern have been identified.

The range of test on a buried pipeline is variable and depends on the conditions of the pipe, the coating and the covering soil. Therefore not in all cases it is possible to achieve a measurement range above 20 metres as shown in the above illustrated examples.
New technologies have improved the performance for testing buried pipelines but the limiting factors can sometimes reduce the range of the inspection to only about 5 meters on either side of the probe ring.

5 – Other Applications

Guided waves can also be applied to many structures different from pipes such as heat exchangers, lamp-posts, risers etc.; the only condition to be respected for GW applicability is a tubular section. Many studies have been carried out about these components.
On Heat Exchangers the test cannot be performed on the external surface of the piping because of their geometry: for this reason specific probes (T-scan) have been developed that can be inserted from the end through a tube sheet (Figure 9).

 (a)  (b)

Figure 9 – .Application of guided waves on heat exchangers (a) and risers (b)

For the inspection of lamp-posts, an important study has been carried out by Carusi et al. [8] proving the efficacy and the limits for testing and elaboration. The most important area to be tested is unfortunately the most difficult to verify: the lamp-post transition

section between the buried and air exposed part. In this area where possible heavy corrosion processes could be active (due to crevice, differential aeration etc.) testing and, above all, the interpretation of data can be strongly influenced by soil and coating effects. Defect localization can only be performed by operators well experienced with guided waves technique and by using suitable inflatable rings.
Figure 10(a) shows a case of real application on a lamp-post with a particular inflatable ring suitable for coupling with the conic shape of the element. A severe corrosion patch (Figure 10 b) has been localized with the guided waves test (Figure 11 – F2)

(a) (b)

Figure 10.Application of guided waves on a lamppost (a) and corrosion defect localization (b)

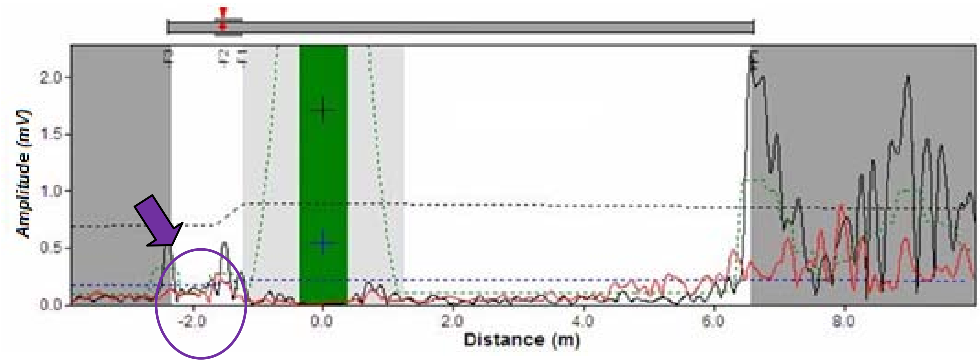


Figure 11 – Interpretation and localization of a corrosion patch (F2)

6 – Structural Assessment

Once the complete measurement set for the structure is available, the evaluation of its structural safety level is fundamental in order to establish its residual life or if a replacement is necessary. For this assessment some original Mechanical/Corrosion Diagrams have been developed (Raoli et al. [9]): these graphs are supported by complex and flexible algorithms that calculate for the spot under examination, the safety margin for the tubular element.

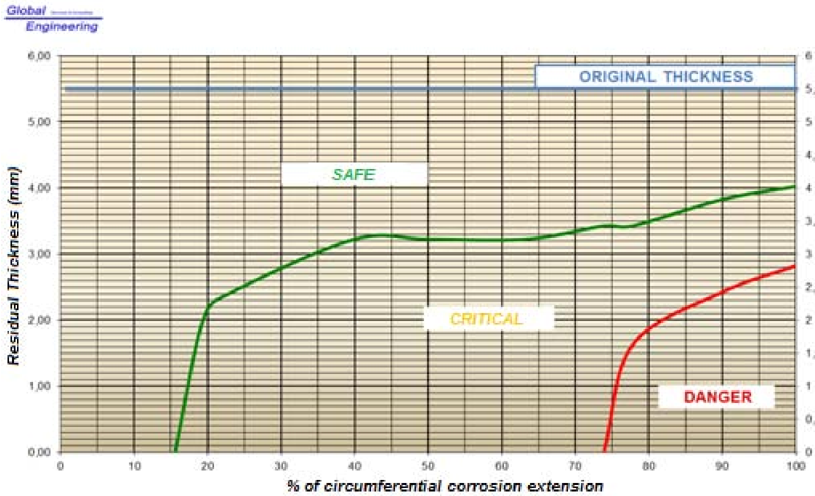


Figure 10. Typical Mechanical-Corrosion Diagram for a lamppost

Considering all the data measured and gathered (pressure, geometrical characteristics, materials, corrosion behaviour etc.) and relevant, applicable standards, the diagram shows the limits of remaining safety margin for the structure under examination.

7 – Conclusions

The Ultrasonic Guided Waves technique enables a rapid screening of long sections of tubular structures for the detection of corrosion and other types of mechanical defects. Tens of meters of pipes can generally be tested from a single location of scanning probe. The implementation of the Ultrasonic Guided Waves technique can substantially reduce the economic impact for inspection and maintenance of such structures if compared with alternative techniques. This technique has been particularly developed for the inspection of above ground structures; the inspection of lamp-post or buried pipelines is to be considered an advanced application of Ultrasonic Guided Waves. The technique is rather user-friendly, but particularly experienced operators are required for the application, and above all for the analysis and interpretation of data. More field experiences and data analyses are needed to better tune the technique to buried pipelines. There are circumstances were this technique is really very useful (e.g. crossings of non piggable pipelines, pipelines in tunnels), the main limitations being the presence of the coating and the soil over the pipeline which unavoidably attenuate the propagation of the signal.

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