Thin wall pipe ultrasonic inspection through paint coating

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Abstract

Classical ultrasonic inspection of welds is currently done for plates thicker than 8 mm. The inspection of but welds in thin walled pipes has considerable implementation difficulties, due to guided waves dominating ultrasonic pulses propagation. Generation of purely symmetric modes, either torsional or longitudinal, requires a circumferential uniform distribution of transducers and dedicated inspection equipment, which are increasing the inspection costs. Moreover, if the surface is paint coated, the received signals are close to the detection level. The present work implies a single transducer, coupled to the painted surface. The proper choice of the guided mode and frequency range, allows the detection of a standard, small diameter through thickness hole. In this way, the inspection of pipe welds can use the same equipment as for thick materials, with only wedge adaptation.

Keywords: Pipe inspection; guided waves; modal attenuation.

1. Introduction

Steel pipes are in most cases covered with protective layers of paint coatings (Koleske, 2012). Ultrasonic pipe inspection in its classical form uses an ultrasonic short pulse propagating perpendicular to the pipe and the coating layer has to be removed. In other instances, when welding seams are investigated, the coating has to be removed and adapted wedge are used to send the ultrasonic beam in search for weld defects. In the last decades another

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ultrasonic technique is emerging, based on guided waves, for which classical references are (Achenbach, 1973), (Miklowitz, 1978), (Lowe et al., 1998). Numerical methods were used to determine the dispersion curves, such as the Semi-Analytical Finite Elements (SAFE) method (Predoi, 2014), (Vollmann & Dual, 1997), or to simulate the guided waves propagation (Jezzine, 2006), (Gsell et al., 2003) using the Finite Elements Method (FEM).

An extended investigation on the defect detectability, with application to Non-Destructive Testing (NDT) is presented in (Cawley et al., 2002). Ultrasonic acoustic energy has to be focused if very small defects are to be detected (Zhang et al., 2006), (Davies & Cawley, 2009).

2. Guided waves in coated pipes

The guided waves propagating in pipes are set in three classes: longitudinal, torsional and flexional. The investigated pipe is made of steel ($c_L=5920$ m/s, $c_T=3255$ m/s, $\rho=7890$ kg/m³ with $c_L$, $c_T$ and $\rho$ the longitudinal, transverse wave velocity and mass density respectively). Pipe outer radius is $R_o=30$ mm and inner radius $R_i=27$ mm. The coating is a paint layer of $H_f=50$ μm thickness. From (Koleske, 2012) and other references, the material elastic properties of this layer can be selected as: Young modulus $E= 64e6$ Pa, Poisson coefficient 0.48 and mass density 2700 kg/m³. Experiments on guided waves propagation, have proved that attenuation exist even for the uncoated pipe. The paint layer is viscoelastic and attenuation can be estimated based on cited references.

The selected reference frame and displacement field, for circumferential order $m$, are given by:

\[
\begin{bmatrix}
    u(r,\theta,z,t) \\
    v(r,\theta,z,t) \\
    w(r,\theta,z,t)
\end{bmatrix} = \begin{bmatrix}
    U(r) \cos(m\theta) \\
    V(r) \sin(m\theta) \\
    W(r) \cos(m\theta)
\end{bmatrix} \exp\left[i(kz - \omega t)\right]
\]

and are shown on Fig. 1. Radius $R_j$ is marking the separating surface between the pipe and the paint layer.

![Displacement field for guided waves in pipes](image)

**Fig. 1.** Displacement field for guided waves in pipes

2.1. Longitudinal waves

Longitudinal waves are axially symmetric, requiring thus a special transducer surrounding the pipe or by impinging ultrasonic pulses at the end of the pipe. The dispersion curves, taking into account the material attenuation are obtained using a recent algorithm (Predoi, 2014).

The well-known modal wavenumbers obtained after solving the dispersion equation are not shown here. The imaginary parts of the wavenumbers, representing the modal attenuation are shown on Fig. 2a in dB/m. All seven modes shown here are increasingly attenuated as the frequency increases.
The most commonly used, L(0,1) and L(0,2) modes reach about 12 dB/m at 2 MHz. The thin paint layer considerably changes the attenuation profile (Fig. 2b). Between 0.5 and 1.3 MHz, there is a “propagation window” with attenuation minima of about 5dB/m as in the non-coated case. At higher frequencies, there is a lower attenuation for the L(0,4) mode and only the L(0,2) mode remains detectable beyond 2 MHz.

Fig. 2. Modal attenuation of the longitudinal modes, for the uncoated pipe (a) and coated pipe (b).

2.2. Torsional waves

Torsional waves are also axially symmetric, with the same requirements for special transducers. Solving for the dispersion equation, the complex values of the wavenumbers are obtained. The obtained modal attenuations are shown on Fig. 3. The torsional waves are extensively used for NDT in recent years. However, on (Fig. 3a) it is shown that pipe material attenuation produces almost the same attenuation as for the longitudinal waves, only more uniformly increasing with frequency. As viscous paint is introduced, frequency domains of very high attenuation become obvious. The T(0,1) mode is the least attenuated. The recommended frequency range for the selected pipe and paint layer is between 0.25 and 1.3 MHz, or 1.6 to 2.3 MHz.

Fig. 3. Modal attenuation of the torsional modes, for the uncoated pipe (a) and coated pipe (b).
2.3. Flexural waves

Flexural waves are generated in most cases by using classical contact transducers. The solutions depend on the circumferential order $m$, corresponding to the number of nodal diameters. Along these diameters, the displacements are null during mode propagation. Since a classical transducer has only a limited contact area, it is clear that the propagating ultrasonic wave will be a superposition of flexural modes of different circumferential orders. The flexural modes (Fig. 4) have similar evolution of the modal damping as the longitudinal modes.

![Fig. 4. Modal attenuation of the flexural modes, for the uncoated pipe (a) and coated pipe (b).](image)

3. Conclusions

The attenuation due to paint layers has been investigated.
Optimal frequency range for each class of guided modes was obtained.
Transducers in contact with the paint layer can be used in the given conditions with higher probability of detection.

Acknowledgements

The present work was supported by the Romanian UEFISCDI Exploratory Research Project PN-II-ID-PCE-2011-3-0512.

References

Achenbach, J.D., 1973. Wave Propagation in Elastic Solids. Amsterdam: North Holland.
Cawley, P., Lowe, M.J.S., Simonetti, C. & Roosenbrand, A.G., 2002. The variation of the reflection coefficient of extensional guided waves in pipes from defects as a function of defect depth, axial extent, circumferential extent and frequency. Proc. Instn. Mech. Engrs. Part C: J. Mech. Eng. Sci., 216, pp.1131-43.
Davies, J. & Cawley, P., 2009. The application of synthetic focusing for imaging crack-like defects in pipelines using guided waves. IEEE Trans. Ultrason. Ferroelectr. Freq. Control, 56(4), pp.759-71.
Gsell, D., Leutenegger, T. & Dual, J., 2003. Modeling three-dimensional elastic wave propagation in circular cylindrical structures using a finite-difference approach. J. Acoust. Soc. Am., 116(6), pp.3284-93.
Jezzine, K., 2006. Approche modale pour la simulation globale de contrôles non-destructifs par ondes élastiques guidées. PhD Thesis. Bordeaux, France: Université Bordeaux 1.
Koleske, J.V., ed., 2012. Paint and coating testing manual. 15th ed. West Conshohocken: ASTM International.
Lowe, M.J.S., Alleyne, D.N. & Cawley, P., 1998. Defect detection in pipes using guided waves. Ultrasonics, 36, pp.147-54.
Miklowitz, J., 1978. The Theory of Elastic Waves and Waveguides. 1 ed. Amsterdam: North Holland.
Predoi, M.V., 2014. Guided waves dispersion equations for orthotropic multilayered pipes solved using standard finite elements code. Ultrasonics, 54(7), pp.1825-31.
Vollmann, J. & Dual, J., 1997. High-resolution analysis of the complex wave spectrum in a cylindrical shell containing a viscoelastic medium. Part I. Theory and numerical results. J. Acoust. Soc. Am., 102(2), pp.896-908.

Zhang, L., Luo, W. & Rose, J.L., 2006. Ultrasonic guided wave focusing beyond welds in a pipeline. Rev. QNDE, 25, pp.877-84.