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Finite Element Model for Multiple Cracks in Steel Pipeline Based on Guided Wave Propagation

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Abstract: Many pipeline defects may reduce the working security as leakage liquid or may be more serious as cause explosion accidents for gas pipeline. This study focus developing the multiple pipeline defect model by guided waves system. The guided wave system consists mainly of one or group of transducers that are placed on the structure to detect the existence of defect. All testing pipe model section sample parameters are the same to 1 m long, 60 mm diameter and the wall thickness is 4 mm. The solid model FEA, the shell-63 element is selected. The pipes structures are studied by ANSYS Version 17.1 for multi cracks pipes structure in different design versions. The simulation result for the defect degree of central angle is used to identify three cracks types and the size of defect and holes will carry out to simulate in the same way.

Key words: Pipeline, crack, guided wave, finite element, identify, holes

INTRODUCTION

Pipeline networks serve as the backbone of the oil and gas supply system, hence, it should be highly reliable and capable in meeting customer's demand for oil and gas products at all times. Usually they exposed to corrosion along the inside the pipeline. Moreover, corrosion makes thinner pipe wall and leaves the pipe disposed to failure. Continuous flow of these products plays a major role in the prosperity and advancement of nations and as such should remain stable and available at all times. Pipe and tubular equipment failure such as in petroleum stations tend to be disastrous, leading to material damage is expensive and the loss of business continuity and even deaths. There is a growing global awareness of this issue. Thus, it is imperative that such network be given the highest consideration and attention at all times to insure its integrity and safety.

Many researchers have studied defect detection methods by using guided waves (Du-Guang *et al*., 1998; An *et al*., 2012). Solved an issue of a harmonic wave propagating in an infinite length hollow cylinder by the elastic theory, successfully explained the frequency dispersion and multi-mode phenomena of the guided wave which is a start sign of the guided wave propagation research (Yang *et al*., 2006). There are many contributing factors to the failure of pipelines that could affect their integrity. One of these contributing factors is the aging of the existing oil and gas infrastructure. Other contributing factors include corrosion, interference from third party, material defects, malfunction and natural hazards. These are key causes that can lead in most cases to undesired consequences. Such consequences may include puncture, rupture and/or leakage of the pipe that may result in injuries, fatalities and catastrophic damage to the surrounding environment and loss of production.

In this study focus on simulate real world damage in the pipe the damage will be designed to simulate perfected, cracks and holes damage that may occur in actual applications in industry. The ANYSIS Software used to simulate thee multiple cracks and holes steel pipelines by to monitoring of critical pipeline system and determine the multiple cracks position and damage level.

Literature review

Typical defects of pipeline structures: The innovative monitoring systems and defects diagnosis techniques should be in place to insure the sustainability of the infrastructure, i.e., pipelines and the associated equipment to insure their integrity and continuity. Generally, Non Destructive Testing (NDT) is used by the industry for assessing pipeline integrity and reliability (Rifai *et al*., 2016). It is an acceptable practice to detect dangerous defects before they can cause catastrophic failure or interruption to production. The main issue with such system is that it is performed on as need basis or at regular maintenance intervals and does not provide on-line monitoring and detection of failures as they happen. The typical defects of pipeline structures are shown in Fig. 1 (Yang, 2009).

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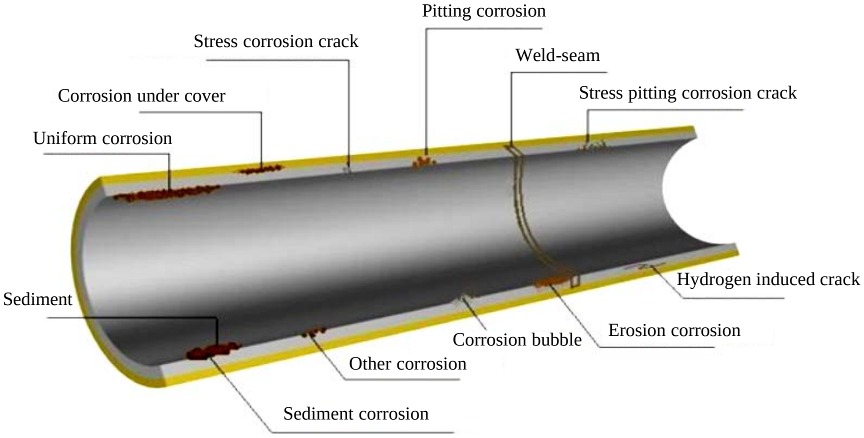

Fig. 1: The pipeline structure schematic of typical defects (Yang, 2009)

Structural Health Monitoring (SHM): The SHM is a technology to provide clear image for critical structural components for better safety and reliability detecting and diagnosing for occurred damage as sensing elements. Common forms of structural damage include corrosion, notches, cracks, holes, etc. If the inspected structure is a pipeline, the abnormalities such as metal loss, holes or cracks will cause a discontinuity to the transmission of the guided wave along the pipe. As a result, some portion of the wave energy is reflected back. The reflected wave can then be analysed to determine the location, type and the extent of the damage (Balageas *et al*. 2006; Giurgiutiu *et al*., 2003).

It has been discussed a number of ways of SHM in literature. Past work has inspected various types of adapters for SHM and different algorithms detect damage and applied of SHM systems to several types of structures. The research shows in this thesis concentrate on guided wave based structural health monitoring using excited lamb waves with piezoelectric transducers to detection and localization for cracks and hole defects in the main body of pipeline. The experiment did not address the sizing of defects. From the literature reviewed, it was not clear if the defect sizing was possible using the techniques presented. There was no clear evidence that pointed any technique for sizing of defects.

Wave propagation in hollow cylinders: Guided waves in cylindrical structures may travel in the circumferential or axial direction. Based on boundary conditions, material properties and geometric properties of the hollow cylinder, the wave behaviour can be described by solving the governing wave equations with appropriate boundary conditions (Agrawal, 2008).

Wave propagation in cylindrical waveguides has been studied on the theoretical and experimental levels by researchers at academic institutions and the industry. Such studies can be found in the literature by Gresil and Giurgiutiu (2015).

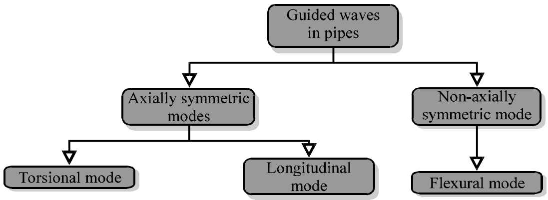

Fig. 2: The types of pipes guided waves

There are basically two categories of guided waves that propagate in a hollow cylinder, the circumferential and the axial guided waves. Under the axial category there are three types of modes generated when waves are propagating along a cylindrical structure. These are the longitudinal, torsional and flexural wave modes as seen in Fig. 2.

The longitudinal and torsional waves inflict symmetrical displacement of particles in the axial direction across the structure while the flexural waves impose a non-symmetric particle displacement along the structure.

Figure 3 provides details of a typical hollow cylinder showing the inner and outer radius and Fig. 4a shown the longitudinal modes propagation where the particle movement is parallel to the wave direction. The longitudinal waves which inflict symmetric particles displacement across the pipe in the radial and axial directions. Figure 4b shows the torsioanl wave modes propagating along the circumferential direction of the pipe and the particle motion is perpendicular to the wave direction. The torsional wave with symmetric particles displacement along the circumference of the pipe. In

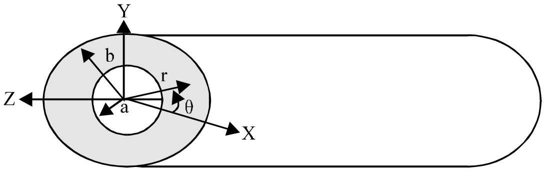

Fig. 3: A cylindrical waveguide with the cylindrical coordinate system (r, θ, z)

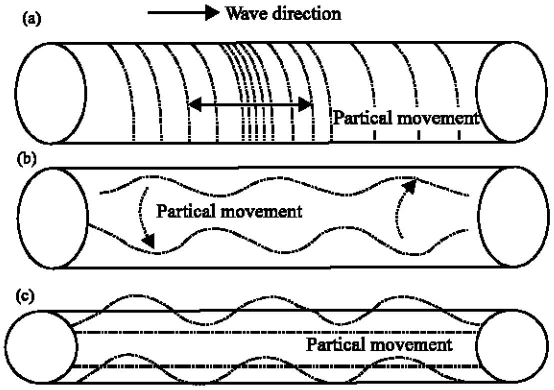

Fig. 4: a) Longitudinal wave with symmetric propagation along the pipe; b) Torsional wave propagation along the pipe in the θ Direction and c) Flexural wave showing nonsymmetrical propagation

Fig. 4c, the flexural guided wave has a non-symmetric mode propagating in the (r, z, θ) directions. For flexural waves, all three displacement components exist, the radial, the axial and the circumferential (r, θ, z). This mode is an essential element in the diagnosis of defects.

These waves suffer a great deal of dispersion and mode conversion that makes it very difficult to analyse. It is extremely important to have a prior knowledge about the physical characteristics of the wave guide, the propagating medium and the defects that may encounter along the propagation path. Such knowledge serves as a prerequisite for the diagnosis of the reflected waves which can be carried out by using special signal processing techniques. These techniques can provide the scharacteristics and features of the reflected waves. Then, the outcome of theses analyses will reveal the existence, location and extent of defects should they exist.

MATERIALS AND METHODS

Proposed numerical model: It is possible to model pipes structures by ANSYS/Multi physics product. The integration of control actions to the ANSYS solution is realized. Each of pipeline design should considered frequency response transient and the modal of the system into account. The material and dimensions of the pipe and types of the signal source and the placement measurement points. To analyse the transient dynamics problem full method will choose to simulate guided the pipe. The time step length is 1.20 μsec, the load action time is 95 μsec and the total propagating time will be 1.22 msec. To identify the three pipeline cracks the conversion mode will also considered flaw echo difficult. The dimension of the experimental perfect pipe and the location of the artificial cracks and hole are shown in Fig. 5a-d.

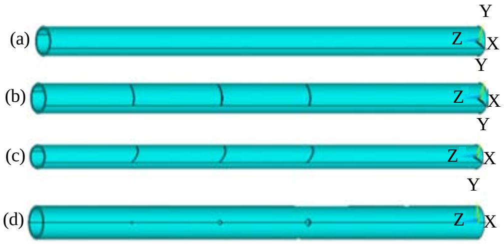

Fig. 5: The three artificial cracks steel pipe

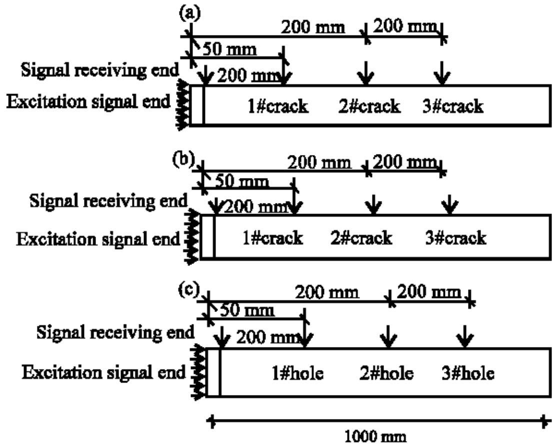

Fig. 6: Steel pipe position of cracks and holes position

Table 1: Cracks location

Vertical cracks location (mm)	1#crack	2#crack	3#crack
cracks position from the pipe end	200	400	600
Cracks width	1.5	2	2.5
Cracks length	25	25	25
Cracks depth	1.5	2.0	4
Sloping cracks location (mm)	1#crack	2#crack	3#crack
position from pipe end	200	400	600
Cracks width	1.5	2	2.5
Cracks length	25	25	25
Cracks depth	1.5	2.0	4
Holes cracks location (mm)	1#hole	2#hole	3#hole
Position from pipe end	200	400	600
Holes diameters	4	8	12
Holes depth	1.5	2.0	4

Figure 6 shown different types and locations of simulate perfect, cracks and holes damage will be used to prove the feasibility of the suggested techniques. The cracks and holes location is shown in Table 1.

RESULTS AND DISCUSSION

To simulate and analyse the transient dynamics using the full method guided waves. The simulation test parameter is chosen as the excitation signal a 6-cycle 70 kHz sine wave, the step length is 1.52 μ/sec, the load action is 100 μ/sec and propagating time is 1.52 m/sec.

Figure 7a and b show healthy pipeline and the concept of active guided wave focusing where time delay-amplitude phasing is applied to the segmented guided wave transducer array to cause constructive interference of the guided wave energy to occur at a given focal point along the pipe. Figure 7c where a uniform wave front is generated and propagates along the pipe with high magnification. Figure 7d where a uniform wave front is generated and propagates along the pipe with low magnification. In Fig. 7, the group speed is calculated to be 5228 m/sec and at the propagation distance of 1 m the passing signal clear appear at 0.1153 μ/sec.

Because of perfect pipeline, no cracks detected where flaw echo easy to identified at the conversion mode. So, in order to eliminate the influence of defect echo by take the average of the receiving signal at each node. Figure 8 show the averaged signal and shows the induced signal from the transmitter to the receiver which directly refers by guided wave propagation.

Figure 9 and 10 show vertical pipeline cracks the uniform wave front is generated and propagates along the vertical cracks pipe.

Figure 11 shows pipe sloping cracks and the concept of axisymmetric guided wave excitation where a uniform wave front is generated and propagates along the sloping three cracks on pipe (Fig. 12).

In Fig. 13, pipeline with holes demonstrating the concept of axisymmetric guided wave excitation where a uniform wave front is generated and propagates along the three holes on pipe. The averaged signal is shown in Fig. 14 and the three holes on pipeline identify by flaw echo.

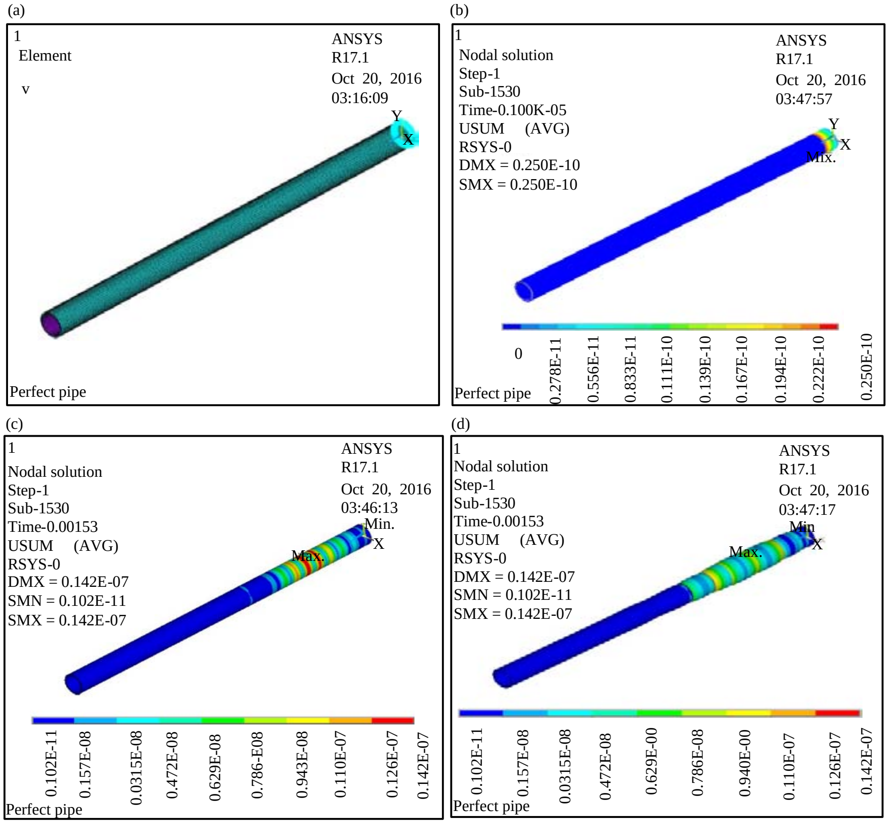

Fig. 7a-d): The meshing model of perfect pipe using FEM simulation demonstrating the concept of axisymmetric guided wave excitation

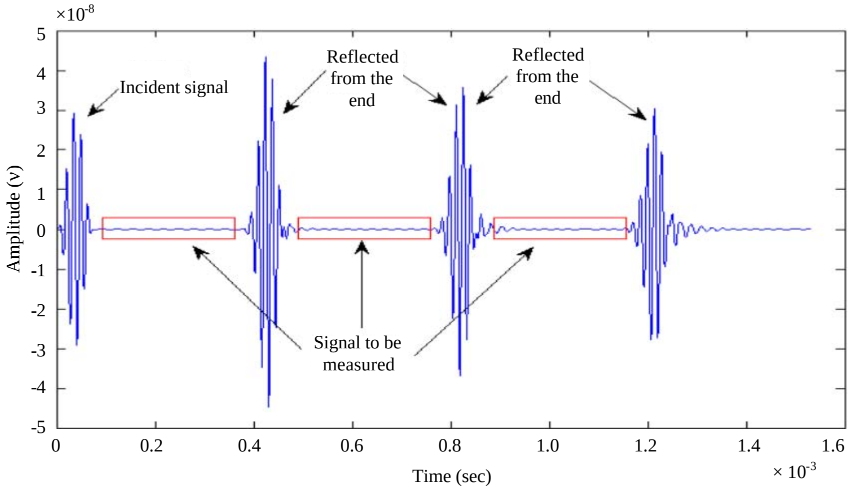

Fig. 8: Steel pipeline displacement-time curves and propagation along 1 m of perfect pipe

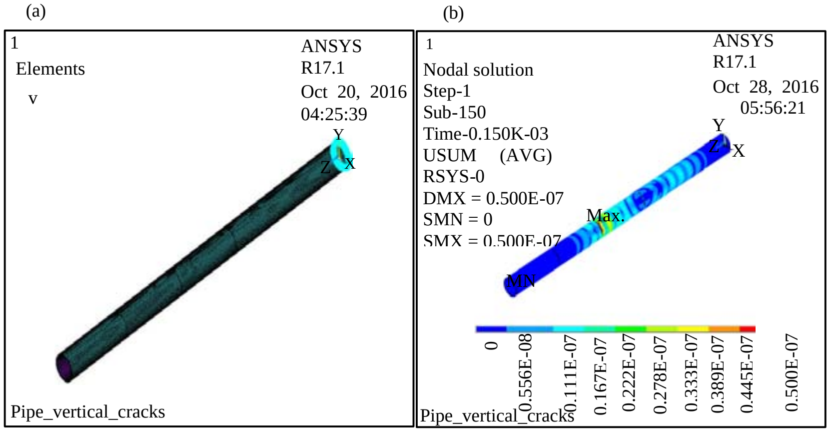

Fig. 9: a, b) The meshing model of vertical three cracks

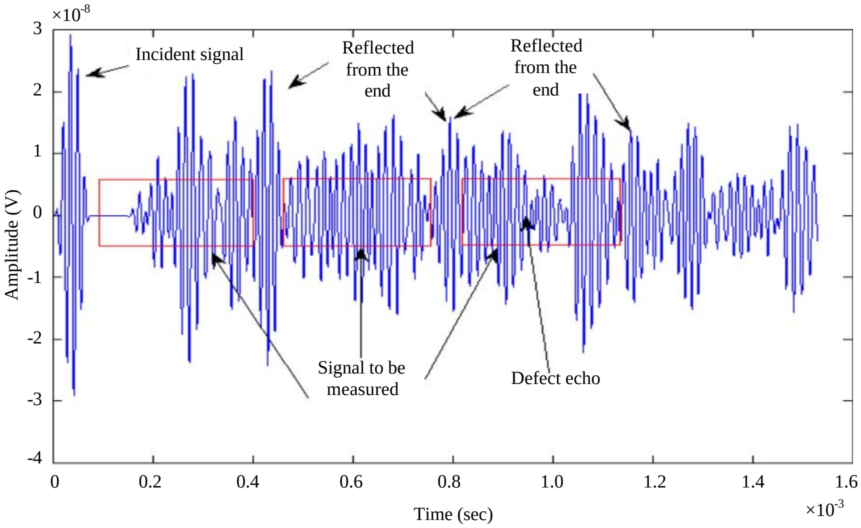

Fig. 10: Steel pipeline displacement-time curves and propagation along 1 m of three vertical cracks on pipe

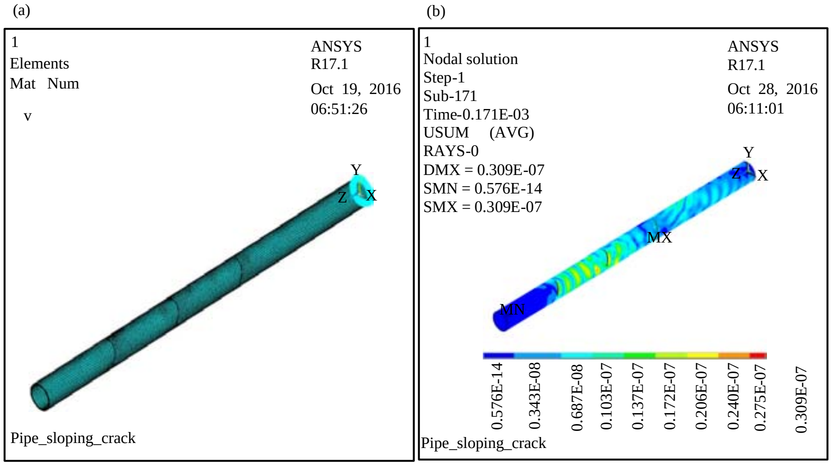

Fig. 11: a, b) The meshing model of vertical three cracks

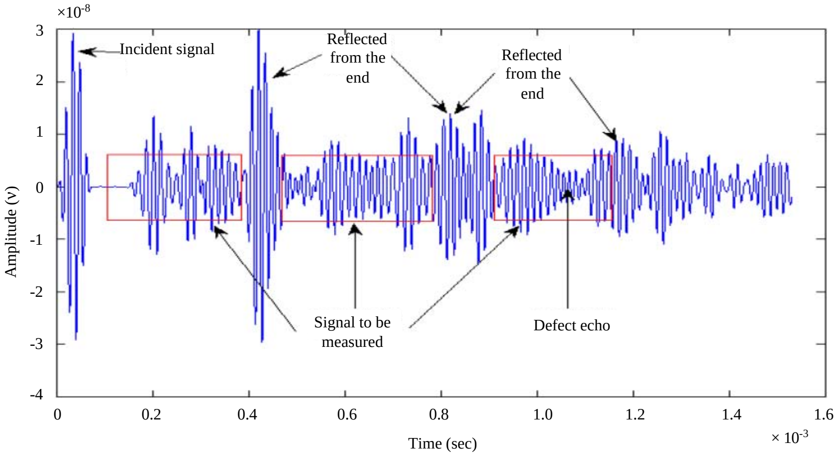

Fig. 12: Steel pipeline displacement-time curves propagation along 1 m of three vertical cracks on pipe

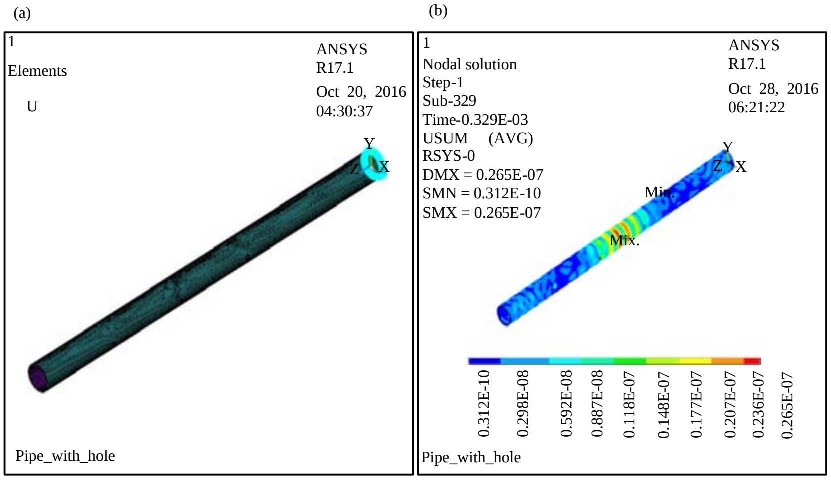

Fig. 13: a, b) The meshing model of vertical three cracks

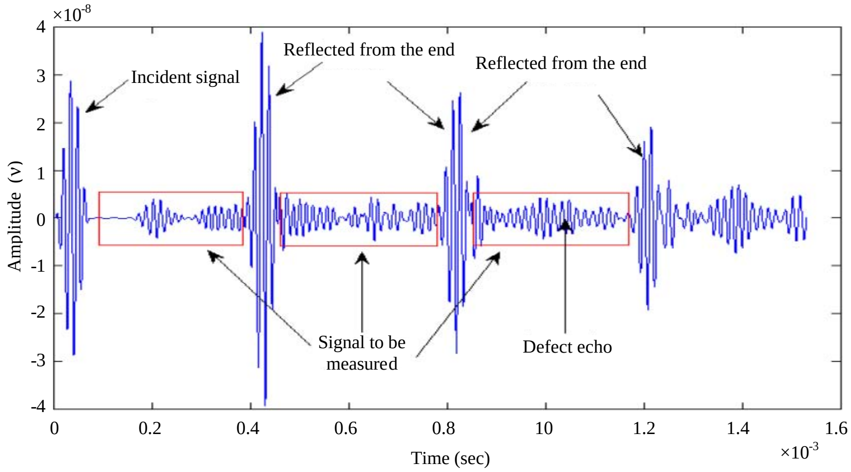

Fig. 14: Steel pipeline displacement-time curves propagation along 1m of three holes on pipe

CONCLUSION

In this study the simulation model, to simplify the pipeline model for 63 sample of different of defects with same wall thickness. However, special concern need to by taking if changing the defects thickness. The simulated holes depth and crack of 2.5, 1.5 and 2.0 mm, respectively. For different defect width the same analysis method to calculate the transmission coefficients and different flaw echo amplitude values. The feasible and accurate depend of numerical guided wave technique depended on relative error.

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