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Next generation guided wave health monitoring for long range inspection of pipes

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ABSTRACT

Shown in this paper are recent accomplishments of robust leading edge technologies in the guided wave technique and the technology transfer to the Gas and Petrochemical Industries. Focusing of guided wave beams is a key for success, compared to conventional axisymmetric excitation. Guided wave scanning and significant sensitivity enhancement are established via the newly implemented focusing scheme. In addition, using both longitudinal and torsional modes is essential to improve sensitivity and reliability in data analysis over the conventional technique based on only longitudinal or torsional. The related theoretical studies and experimental data are also presented along with field test results for confirmation.

1. Introduction

Ultrasonic guided wave propagation in hollow cylinders (pipes) has been studied from a theoretical point of view for over a century by people such as Rayleigh, Love, Mirsky, Herrmann, Ghosh, Gazis, Rose, Cawley, and many others. Because of computational limitations, the first practical nondestructive evaluation application of guided wave ultrasound for piping did not occur until the 1990's (Alleyne & Cawley, 1996; Alleyne, Pavlakovic, Lowe, & Cawley, 2001; Barshinger, Rose, & Avioli, 2002; Cawley, Lowe, Alleyne, Pavlakovic, & Wilcox, 2003; Ditri, 1994; Ditri & Rose, 1992; Kwun & Holt, 1995; Rose, 2002; Rose, Jiao, & Spanner, 1996; Rose, Rajana, & Carr, 1994). It was shown that a long length of pipe could be inspected from a single probe position. Since this time, guided wave NDE techniques have evolved significantly. The most significant of these revolve around the ability to control segments of a guided wave producing phased array. (Li & Rose, 2001, 2002; Rose, Sun, Mudge, & Avioli, 2003; Sun, Rose, Song, & Hayashi, 2003; Sun, Zhang, & Rose, 2005; Zhang, Rose, & Gavigan, 2004; Zhang, Luo, & Rose, 2005; Zhang, Gavigan, & Rose, 2006).

2. Phased array guided wave ultrasonics

2.1. Natural focusing and FAT

Advances in electronic engineering and computational speed have enabled NDE engineers to develop a phased array for guided waves. A typical configuration is shown in Fig. 1.

This configuration will be the configuration used throughout the remainder of the paper. Since each of the octants is individually addressable, octants may be also used in pairs to produce quadrant excitation (each quadrant ∼ 90° of arc). When all octants are excited simultaneously, the loading is axisymmetric and is typically called "axisymmetric".

Additionally, both longitudinal excitation (L [0, 1], L [0, 2] modes) and torsional excitation may be available (T [0, 1] mode). A limited pipe inspection may involve an axisymmetric torsional mode configuration.

Beyond axisymmetric excitation, is the ability to focus guided wave energy. This is achieved by both by frequency tuning and by timing the firing and excitation amplitude of the individual elements of either a quadrant or octant based phased array.

By frequency tuning, we mean, varying excitation frequency over a range and noting where responses are maximized. Frequency tuning with the axisymmetric mode is typically performed as a first step of an inspection.

Fig. 2 shows some results of frequency tuning. The results were obtained using axisymmetric loading of 16″ coated pipe with a 3%

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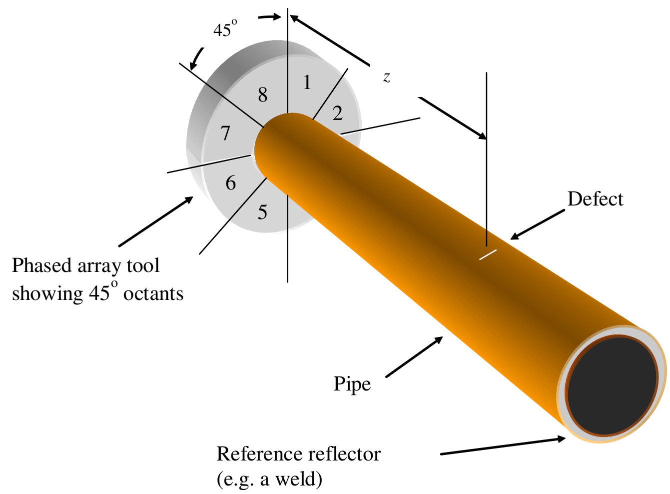

Fig. 1. Illustration showing the locations of 45° phased array loading elements and the location of the notch defect.

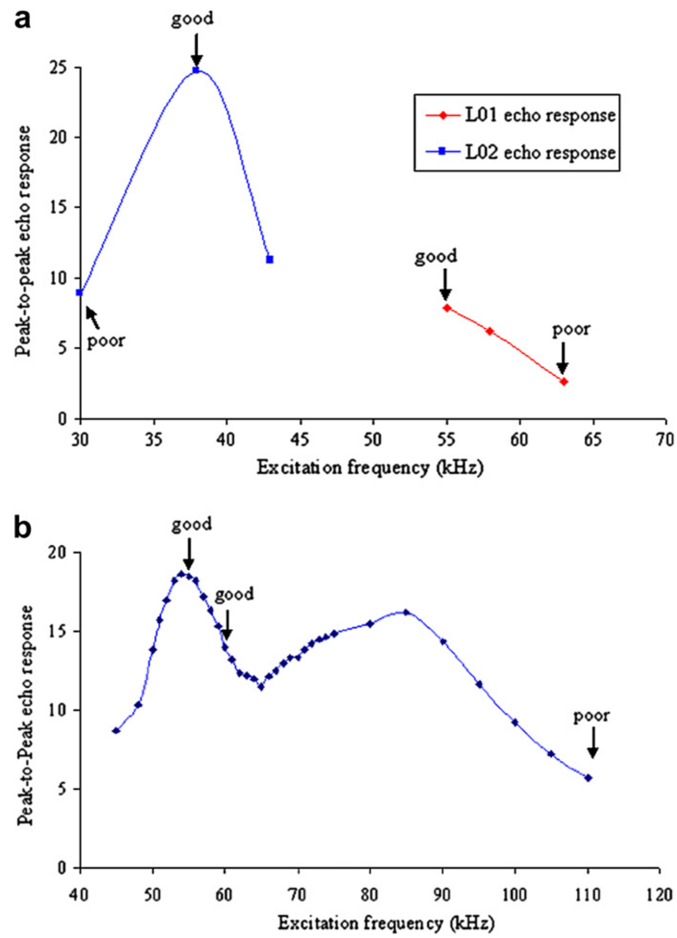

Fig. 2. (a) L [0, 1] and L [0, 2] frequency tuning responses from a defect in a 16″ pipe, (b) T [0, 1] frequency tuning response from the defect(same as above) in the 16″ pipe.

CSA transverse defect located 22 ft away from the phased array. This illustrates the point that, in terms of detection, defect responses are frequency dependent.

To carry this further, to "natural focusing" as an NDE tool, partial loading (only ×degrees of the circumference are excited) should be considered. It is known that as guided waves generated from this loading exhibit varying displacement profiles along the axis of the pipe. These profiles are a function of the pipe geometry, outer diameter and wall thickness, excitation frequency, the type of mode, and distance from the loading.

Fig. 3 shows typical profiles. As the figure shows some may have multiple lobes where as others may have a single predominant lobe. Excitation frequency determines the displacement profile. Fig. 4 shows how natural focusing can occur. Partial loading is used in conjunction with frequency tuning to find the maximum response (if any).

Considering that the loading can be applied at different circumferential angles around the pipe when using a phased array, there will be maximums at various locations due to frequency, and

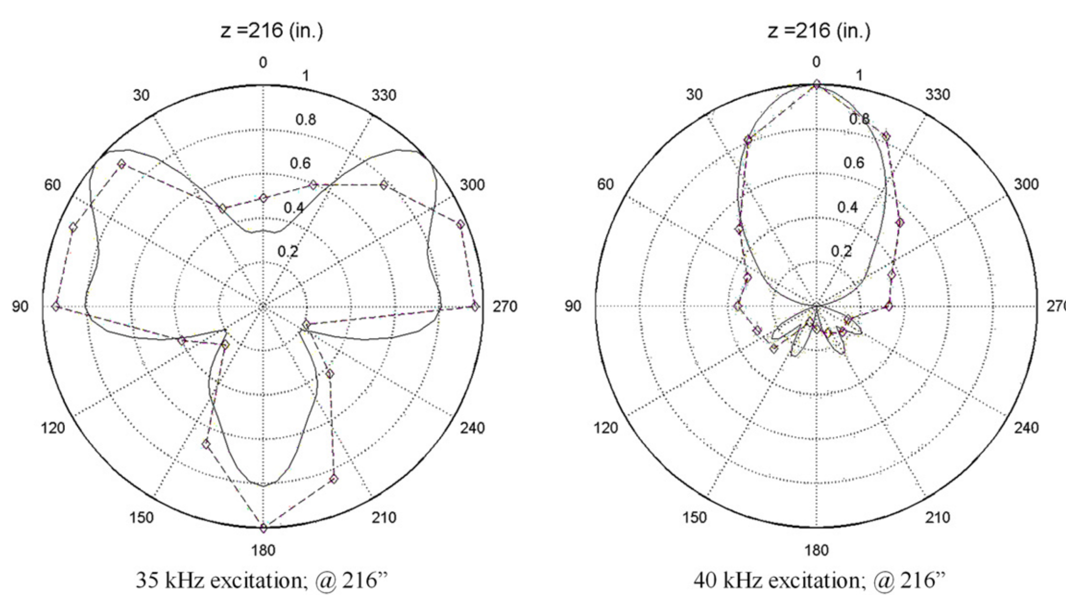

Fig. 3. Displacementprofiles for a 16″ coated pipe at 216″ at different frequencies. Note high energy natural focal points at 50°, 180°, and 310° at 35 kHz. If a defect were located at 0°, when 40 kHz was used it would a produce a maximum response (natural focus). The solid lines are theoretical. 85° loading was used at 45° to acquire the data shown as small circles in the figures. The measurements were performed at the FBS, Inc. laboratories. Theory and experiment agreed quite well.