PHASED ARRAY GUIDED WAVE FOCUSING IN PIPE

Z. Sun and J.L. Rose
The Pennsylvania State University, University Park, Pennsylvania, USA

Abstract: Guided waves propagate in pipes for long distances, which make it prospective in pipeline inspection. With the aid of a circumferential phased array transducer guided wave can be controlled to focus energy in both circumferential and axial directions. Wave energy focusing not only enhances signal to noise ratio, power penetration ability but also provides information on circumferential location and width of defects. Experimental results based on commercial pipeline inspection system are displayed followed by discussions and suggestions on inspection system modification.

Introduction: Guided wave propagating in pipe axial direction can be categorized into axisymmetric modes and non-axisymmetric modes, so called flexural modes [1]. Axisymmetric modes, both longitudinal and torsional modes have been applied to long-range pipeline inspection for more than two decades. Commercial pipeline inspection systems are also developed based on different excitation principles, such as dry couple hertz contact transducer for both longitudinal and torsional modes, EMAT (electromagnetic acoustic transducer) mainly for torsional modes, and MsS (magnetostrictive) transducer mainly for torsional modes.

Recently non-axisymmetric guided wave modes have been investigated by Li and Rose [2] for flexural longitudinal modes, Sun and Rose [3] for flexural torsional modes. According to mode physical characteristics, such as dispersion curves and wave structures every axisymmetric mode can be combined with the corresponding non-axisymmetric modes to form a group, so called flexural longitudinal or flexural torsional groups. Each group of modes can be excited by selecting certain parameters, such as frequency and frequency bandwidth, incident angle or element spacing [4], circumferential loading angle and axial loading length [1]. Each specific group of modes exhibits a certain distribution of displacement in circumferential direction, so called angular profile. Depending on the angular profile wave energy shows a specific pattern, which has maximum energy focuses at some circumferential directions and minimum at some other directions. This phenomenon is called natural focusing, which refers to the energy naturally focusing at certain circumferential directions.

To control the natural focusing characteristic a four-dimensional parameter tuning process has been developed [1]. A typical example is to focus energy at 180 degree some axial distance with transducer loaded around 0 degree by parameter tuning. To fully exploit flexural mode focusing potential a phased array focusing algorithm has been developed to enhance the energy focusing by controlling amplitudes and time delays for array elements [5].

Results: With the aid of a circumferential phased array transducer wave energy can be controlled to focus at pre-described locations in both circumferential and axial directions. The advantages of guided wave focusing in pipe are listed as follows,

- Signal to noise ratio Improvement;
- Power penetration ability enhancement;
- Possibility of defect detection improvement;
- Defect false alarm reduction;
- Quantitative defect characterization: defect circumferential length, location;

Phased array focusing experiments were carried out based on Teletest ® guided wave inspection system. A set of transducer tool mounted on a 16" pipe is shown in figure 1. It contains forty-four transducer modules, each of which has an electric lead and can be grouped with other modules. To carry out phased array focusing experiments in the following, forty-four modules were grouped into four channels with eleven modules in each channel. Firing all four channels at same time would generate an axisymmetric guided wave mode. Feeding time delays and amplitudes to four channels would enable to focus wave at specific locations. Time delays and amplitudes are calculated based on the phased array focusing algorithm. Each module has three transducer elements equally spaced in the pipe axial direction. Element spacing and frequency are determines depending on guided wave mode choice. A saw cut defect with 3% cross-section area (CSA) on a 16” Schedule 30 steel pipe is shown in figure 2. Distance between transducer and the saw cut defect is 20 feet and the defect is aligned with the transducer in the middle of quadrant 1.

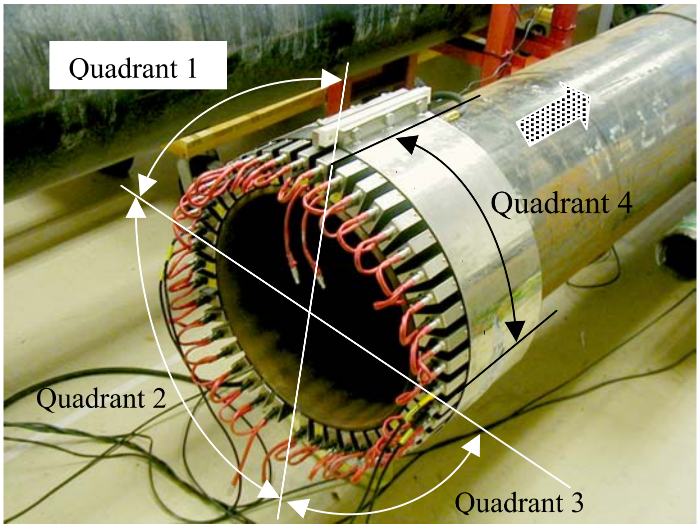
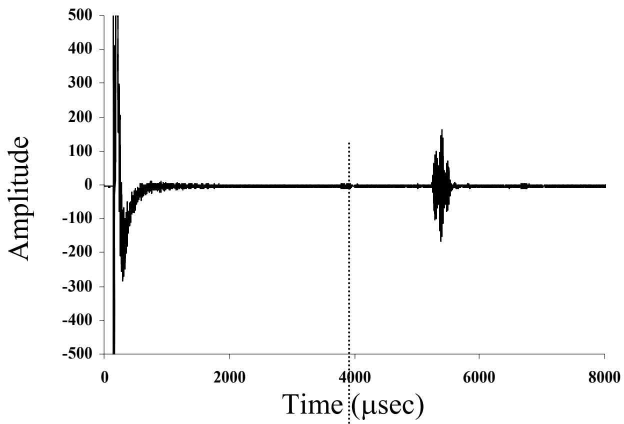
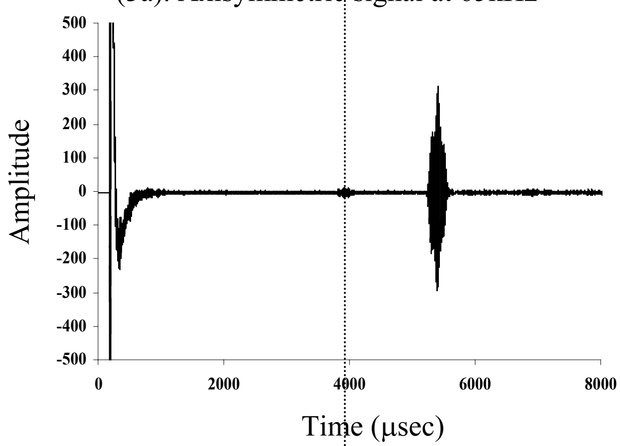


Figure 1. A set of transducer tool mounted at a 16” Schedule 30 steel pipe end.

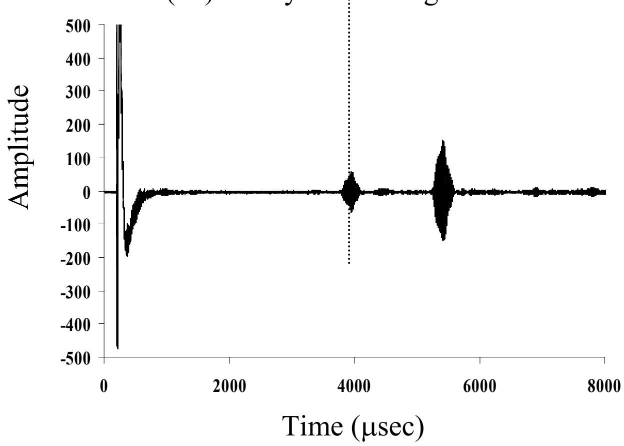
Figure 2. 3% cross sectional area saw cut defect on a 16” steel pipe



(3a). Axisymmetric signal at 65kHz

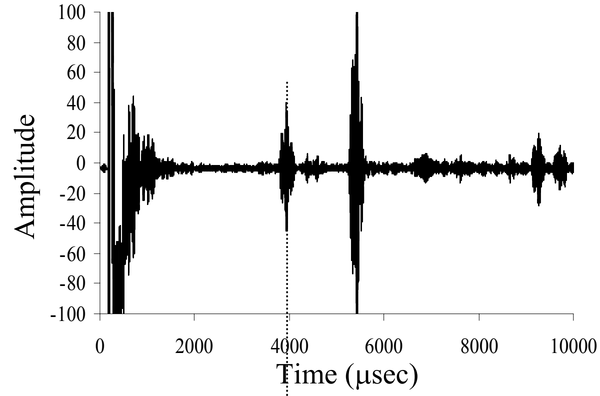


(3b). Axisymmetric signal at 55kHz

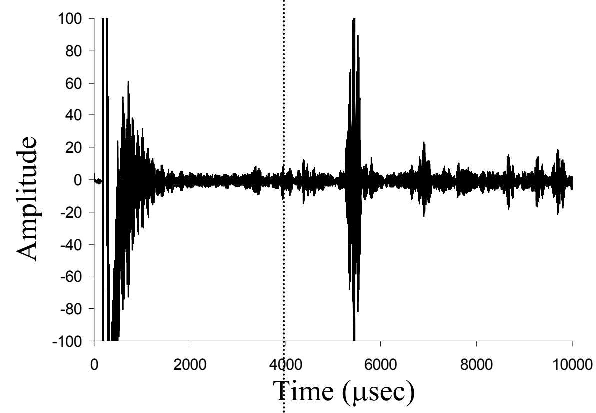


(3c). Phased array focusing signal at 55kHz

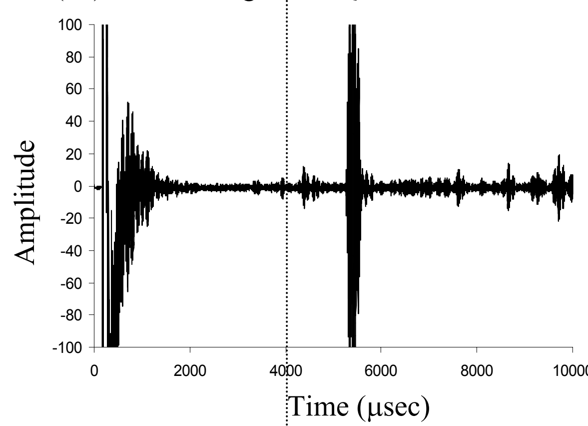
Figure 3. Comparison of three inspection results on 16” steel pipe.



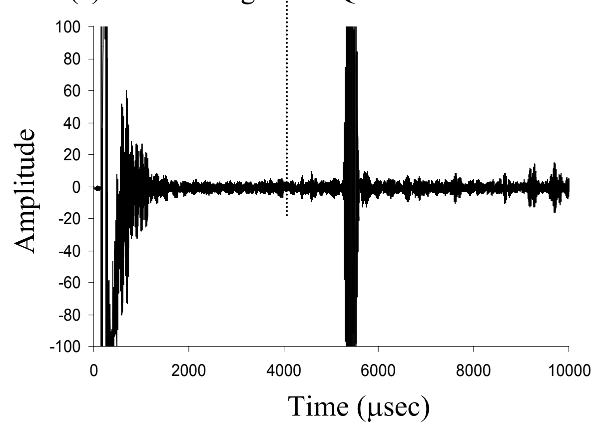
(4a). Focused signal on Quadrant 1 at 55kHz



(4b). Focused signal on Quadrant 2 at 55kHz



4(c). Focused signal on Quadrant 3 at 55kHz



(4d). Focused signal on Quadrant 4 at 55kHz

Figure 4. Phased array focusing signals focusing on four quadrants.

Inspection results with flexural torsional modes, T(0,1) – $F_T(10,1)$ group are displayed in figure 3 and 4. The phase velocity and group velocity of this group of modes are close to 3.23 mm/□sec in steel pipe. Figure 3 shows three pulse echo inspection results with continuous improvement on the defect echo response. 3a gives the axisymmetric result at 65kHz, 3b at 55kHz and 3c shows the phased array focusing signal focusing at 20 feet, quadrant 1 the saw cut defect location at 55kHz. The defect echo amplitude increases by 5.5dB from (a) to (b) and 6.8dB from (b) to (c). Figure 4 shows the phased array focused signals focusing on quadrant 1 - (4a), 2 – (4b), 3 –(4c) and 4 –(4d), respectively. Comparing the signals (a) to (d) the saw cut defect circumferential location can be verified since only quadrant 1 gives high echo response while all other quadrants have no obvious echo responses from the defect.

Discussion: From the inspection results shown in figure 3 a general inspection sequence can be summarized as follows,

1. Axisymmetric inspection at one frequency to set up a baseline;
2. Frequency tuning with axisymmetric inspections and find the optimal frequency for a certain application;
3. Phased array focusing inspection to enhance defect echo amplitude.

In some cases, especially when frequency is higher than 300kHz and pipe diameter bigger than 4 inch there is a certain axial range from the transducer, in which single element angular profile does not change much. That means wave energy stays in certain circumferential direction while wave propagates. Phased array focusing has little enhancement in this range compared to axisymmetric inspection since waves coming out of different elements do not interfere with each other much. Axisymmetric excitation or single element sweep inspection would be suitable here.

Figure 4 shows another advantage of phased array focusing, defect location in the circumferential direction. By sweeping focusing point along pipe circumference defect echo amplitude would increase when the focusing point moves closer to defect. Increasing the number of channels would make it possible for narrow focusing beam, which further enhance defect circumferential resolution.

Conclusions: Phased array guided wave focusing has been carried out in pipe inspection based on modified commercial pipeline inspection system. Focusing effect and its advantages are discussed. To further exploit the focusing potential element angular profile characteristics, axial and circumferential focusing profiles will be investigated.

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References:

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