Mechanical Systems and Signal Processing 78 (2016) 107–117

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Quantification and localization of internal pipe damage

Bouko Vogelaar [a,*], Michael Golombok [b]

[a] Department of Mechanical Engineering, Eindhoven University of Technology, Groene Loper 15, 5600 MB Eindhoven, The Netherlands
[b] Shell Global Solutions International B.V., Kessler Park 1, 2288 GS Rijswijk, The Netherlands

A R T I C L E I N F O

Article history:
Received 17 December 2014
Received in revised form
9 July 2015
Accepted 8 October 2015
Available online 23 October 2015

Keywords:
Structural health monitoring
Guided waves
Piezoelectric transducers
Pipe damage
Time-frequency analysis

A B S T R A C T

Internal pipeline defects are detectable and locatable from guided acoustic wave reflections using sensors mounted on the outer wall of a pipe. We demonstrate pipeline integrity monitoring with only two single acoustic sensors. Multi-mode dispersion imaging of shear displacement shows that the pure torsional mode is the only wave that survives axisymmetric pipe reflection. A reduction of 20% of the reference reflection is measured for a damage of half the wall thickness. This natural filtering is used to quantify and locate internal pipe damage.

1. Introduction

Guided wave monitoring of pipelines is hardly practiced in the petrochemical industry system [1–6]. The development of a guided wave system requires monitoring based on the reception of guided waves by devices along the pipelines. The structure acts as a waveguide and its geometry restricts the amount of possible wave types. Three wave types are distinguished by their prevailing direction of particle displacement in a cylindrical geometry [7]:

- longitudinal waves have dominant axial polarization and no circumferential component;
- torsional waves have pure circumferential polarization;
- flexural waves have a strong radial component to bend the pipe and consequently a minor circumferential and axial component.

Each wave type contains numerous wave modes, specified by the number of wavelengths that fit around the pipe circumference. All wave types and modes propagate at a characteristic speed, dictated by the pipe material, pipe wall thickness and diameter. Recent studies have successfully determined the extent and severity of damage from signal processing [8–10]. Previous studies used an array for the emission and reception of specific guided wave modes [11–15]. The systems require baseline subtraction [16–18]. To receive readable echoes from weak reflectors, high energy spikes or chirp pulses are excited [19,20]. Pure modes are excited that are most sensitive to specific damage [21,22]. The drawbacks are pipe- and fault-dependent sensor settings [23]. Great precision is required to control wave type, mode, and directionality [24,25].

* Corresponding author. Tel.: +31 40 247 2135.
E-mail address: b.b.s.a.vogelaar@tue.nl (B. Vogelaar).

http://dx.doi.org/10.1016/j.ymssp.2015.10.011
0888-3270/

The approach here is different, since we use only two normal incidence shear wave transducers for internal damage localization and assessment. In present paper, the emitting and receiving transducers respectively excite and detect a number of modes that exhibit a circumferential displacement component. Consequently, the interaction between all modes with a circumferential displacement component and different types of damage ensures a robust damage identification and localization [26–29].

The aim of this paper is to present a self-filtering, internally-referenced processing method to locate an internal damage in the pipe wall using only two acoustic sensors. First, we define the pipe structure and fault. In Section 2, we generate a resonant like multi-mode signal that is naturally strong, so carrying over long distance. Section 3 describes which wave mode naturally 'survives' reflection from the recorded guided wave signals. Section 4 shows that this strong surviving mode is sensitive to induced damage. Finally, we demonstrate that this signal defines the damage location.

2. Experiment

2.1. Pipe selection

The best-candidate wave for damage localization depends on the structure tested and the characteristics of the damage. Experiments are performed on two straight cylinders of 2 m length with different diameter and wall thickness: 80 × 2.0 mm and 75 × 2.5 mm (outer diameter x wall thickness), respectively. Both cylinders are seamless carbon steel pipes with open axisymmetric ends.

2.2. Acoustic system

The system presented here only uses two piezoelectric shear wave transducers mounted on the pipe, one emitter and one receiver. The emitting and receiving transducers contain a piezoelectric shear element, sensitive to transverse displacement. The spectral amplitude at the applied frequency of 15 kHz is 1/5th of the amplitude at the transducer center frequency of 100 kHz. The transducer element size is 1 in. diameter; its flat face is mounted on the curved pipe wall without wedges or shoes preventing reverberations.

An arbitrary wave form generator feeds the emitter with a single sine pulse of 15 kHz. This frequency is found to yield a strong signal, since the associated torsional wavelength is near the pipe nominal circumference (0.2 m) and resonance like performance at the torsional ring frequency occurs. The detected signal is recorded over 5 ms by a digital oscilloscope with a sampling interval of 500 ns. The Nyquist frequency of the equipment of 1 MHz prevents aliasing. Typically 16 or 128 successive recordings with a burst period of 100 ms are captured and transferred to a computer for offline signal processing.

2.3. Acquisition

2.3.1. Mode determination

The emitter is left in place during this experiment at the pipe end A, see Fig. 1. The application of a two-dimensional Fourier Transform technique for one of our calibration analyses (see below), necessitates the signal recording at different spatial positions along the pipe, so the single receiver is subsequently moved lengthwise along the pipe. The first receiver position is at 0.1 m from pipe end A. The next series is captured after moving the receiver over 0.1 m and repeated alike to collect measurements at 20 axial positions. Equidistant steps of 0.1 m are about half the torsional wavelength, so spatial aliasing is expected. (The wavelength is the ratio of the shear wave velocity (3.2 km/s for carbon steel) and frequency.)

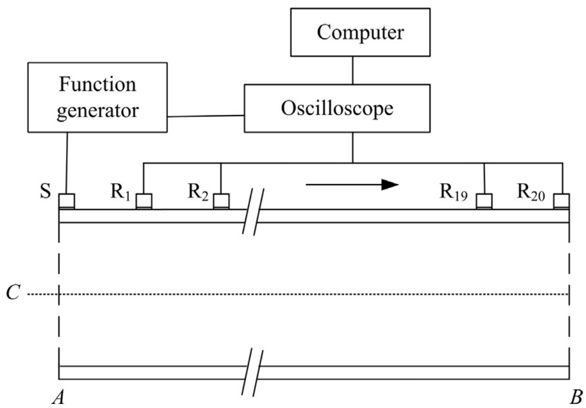

Fig. 1. Multi-channel acoustic set-up on a schematized open-cut pipe. S is source postion. R_1 to R_{20} are twenty receiver positions. A is the pipe's near end. B is the pipe's remote end. Line C is the axis of the pipe. Not to scale.