Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 70 (2014) 573 – 582

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Computing and Control for the Water Industry, CCWI2013

Transient wave-blockage interaction in pressurized water pipelines

H.-F. Duan[a,*], P. Lee[b], M. Ghidaoui[a]

[a]*Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong.*
[b]*Department of Civil and Natural Resources Engineering, The University of Canterbury, Christchurch, New Zealand.*

Abstract

Transient flows are commonly encountered in pressurized water pipelines and have been studied for the purpose of systems design as well as defects detection and management. The representation and analysis of the transient response in the frequency domain is an attractive approach for fault detection due to its high noise tolerance and the linearized equations allows for the clear analytical characterization of system behaviour. Recent studies have demonstrated that an extended partial constriction of the pipe flow area causes changes in the system resonant frequencies and these changes can be used for locating and sizing partial blockages in pipes. Despite the successful application of this technique under field conditions, so far there is little work on the link between the changes in the system resonant conditions and the wave-blockage interaction. This paper provides a fundamental basis for the observation that unlike localised, discrete blockages, an extended blockage creates changes in the system resonant frequencies. Analytical methods using wave perturbation analysis and transfer matrix are shown in this study, and the obtained results are compared with numerical simulations and experimental data. The analytical analyses are used to explain the blockage-induced frequency shifts and to provide insights for its practical applications in pressurized water pipelines.

Keywords: Transients; water pipeline; wave-blockage interaction; resonant frequency shift; transfer matrix; wave perturbation analysis

1. Introduction

Partial blockages are common in engineered as well as natural pressurized conduit systems that transport liquids and are created from a myriad of physical and chemical processes such as material deposition, tubercles (rust),

* Corresponding author. Tel.: +852-23588847; fax: +852-23581534.
E-mail address: ceduan@ust.hk

doi:10.1016/j.proeng.2014.02.063

scales, plaque, bio-fouling, ice-formation in cold climate, and inadvertently throttled inline valves. Blockages in engineered systems result in the wastage of energy and financial resources, reduction in the pipe carrying capacity and the increased potential for contamination. It is therefore important detect such anomalies and deal with them quickly before they can cause severe problems and damages.

Nomenclature

A	pipe cross-sectional area
a	wave speed
F	frequency change
h	pressure head in the frequency domain
I	amplitude of incident wave
K	head loss coefficient of junction at blockage
k	wave number
L	total length of pipeline
l	length of pipe section
m	integer number
P	pressure in the time domain
Q	discharge in the pipeline
R_f	coefficient of frictional damping
R	amplitude of reflection wave
s	intermediate coefficient in Eq. (10)
t	time
x	distance from upstream reservoir
Y	hydraulic impedance
ΔH	minor head loss at junction
μ	coefficient of wave propagation
ω	angular frequency
ξ	restriction coefficient of blockage
$_{J0}$	subscript for indicating the steady value at junction
$_{1, 2, 3}$	subscripts for indexing the pipe section

Transient-based methods, where a transient signal is injected into the conduit and the response measured at specified locations, is a promising approach for detecting defects in pipes and have been used in the detection of discrete blockages, leaks, and the assessment of pipe wall condition (Liggett and Chen 1994, Brunone 1999, Vitkovsky et al. 2000, Wang et al. 2002 and 2005, Ferrante and Brunone 2003, Covas et al. 2004, Mohapatra et al. 2006, Sattar et al. 2008, Lee et al. 2006 and 2008, Stephens 2008, Colombo et al. 2009, Duan et al. 2011a, 2012 and 2013, and Meniconi et al. 2009, 2011 and 2013). The tenet of this approach is that a measured pressure wave signal in a conduit is modified by, and thus contains information on, the conduit properties.

Brunone et al. (2008), Stephens et al. (2008) and Duan et al. (2012) proposed that blockages in pipes can be divided into two categories—discrete and extended blockages—according to their relative length to the total pipe length. Contractor (1965) showed that a discrete partial blockage, in the form of an inline orifice or valve, causes a partial reflection of waterhammer waves where the amplitude of the reflected wave is related to the constriction severity of the orifice and arrival time of the reflected wave at the measurement station provides the blockage location. The findings of Contractor (1965) have been validated in Meniconi et al. (2009 and 2011). Wang et al. (2005) showed that a discrete blockage creates a frequency dependent damping of the transient trace, which can be used for locating and sizing the blockage.. Mohapatra et al. (2006), Sattar et al. (2008) and Lee et al. (2008) showed that a discrete blockage in a pipe system imposes a periodic pattern onto the amplitudes of the system resonant responses and developed a technique for locating and sizing discrete blockages on the basis of this pattern.