Transient Response Analysis for Fault Detection and Pipeline Wall Condition Assessment in Field Water Transmission and Distribution Pipelines and Networks

by

Mark Leslie Stephens

February 2008

A Thesis Submitted for the Degree of Doctor of Philosophy

School of Civil and Environmental Engineering
The University of Adelaide, SA 5005
South Australia

Abstract

Condition assessment of water distribution pipeline assets has been the focus of water authorities for many years. Transient response analysis, including Inverse Transient Analysis (ITA), provides a new potential method for performing specific non-destructive tests that gives much broader information regarding the condition of pipelines than existing technologies. The basic concept involves inducing a transient in a pipeline and measuring its pressure response. The pressure response is theoretically a function of the condition of the pipeline wall (which is the fundamental characteristic related to the propagation of a transient wavefront) and reflections and damping from any fault that may be present. If an accurate transient model of the pipeline under examination can be developed then it may then be possible to isolate particular parameters in it (relating to the wall thickness of the pipeline or faults such as blockages, air pockets and leaks) and fit these to give optimal matches between the model predicted and measured response of the pipeline. This process is often referred to as inverse analysis (and hence the derivation of the name Inverse Transient Analysis).

While a significant amount of numerical and laboratory investigation has been carried out focussing on the use of ITA for leak detection, few field studies have been undertaken. The goal of this research is to determine whether transient response analysis and Inverse Transient Analysis (ITA) can be applied in field situations to provide useful information regarding the condition of pipeline walls and the presence of specific faults such as blockages, air pockets and leaks. Numerous field tests are conducted on large scale transmission pipelines, small scale distribution pipelines and a distribution network in order to obtain a view of the nature of the measured transient responses at each scale and to identify any common characteristics. The capacity of existing transient models to replicate the measured responses is then assessed and they are found to be generally incapable of replicating the field data. Given the physical complexity of field pipelines, and a number of complex phenomena that have been traditionally neglected, this result is not unexpected. The research proposes the development of transient models that can be calibrated to measured responses. These models incorporate mechanisms for including mechanical dispersion and damping and follow precedents developed in other fields of engineering in which damping of transient phenomena is significant. Inverse methods are used to calibrate the proposed transient models using the measured field responses. Similar inverse methods are then used to perform transient response analysis and/or ITA to appraise the wall condition of a transmission pipeline and locate and characterise artificial blockages, air pockets and leaks on transmission and distribution pipelines and networks.

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give my consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying.

Signature: ....   Date: ....

Mark Leslie Stephens

Acknowledgements

I would like to express my gratitude and thanks to:

- Associate Professor Martin Lambert and Professor Angus Simpson, my supervisors, for giving me the opportunity to undertake this research and their continuous encouragement, technical assessment and personal support in the field
- Ex-postgraduate student Dr John Vitkovsky for his friendship, patience during numerous discussions, improving my knowledge of transient analysis, field assistance and providing technical review and feedback over the duration of the research
- Professor Emeritus James Liggett for providing constructive feedback, rigorous technical assessment and overall direction to the research
- Professor George Kuczera for the inverse analysis software NLFIT and for guidance and mentoring from time to time
- Ex-postgraduate student Dr Pedro Lee for his friendship and feedback over the duration of the research and for providing some more light-hearted entertainment when assisting in the field tests
- Current postgraduate student Young-Il Kim for his friendship and support during field testing
- Ex-postgraduate students Dr Xiao-Wang and Dr Dalius Misiunas for their assistance during technical discussions and field tests
- Laboratory technical staff Greg Atkins and Jeffrey Hiorns, in particular, for help creating a variety of transient inducing mechanical devices
- Bruce Lucas for his interesting practical ideas and field support and instrumentation technical staff Ian Cates and Stan Woithe for teaching me something about electrical circuits
- United Water International for financial and practical field support and in particular Dr Stephanie Rinck Pfeiffer of “Research and Development” and Mr Jon Houston (now retired) of “Operations”
- Dr John Nixon for his enthusiastic support and technical review and feedback over the duration of the research

- the South Australian Water Corporation for access to pipelines and encouragement and practical support through Mr Jim Braendler and Mr Greg Milsom
- the Australian Research Council for financial funds expended on this and associated projects

I would also like to thank my family

- my mother and father, Anne and Ted, for supporting my education and fostering scientific curiosity in me
- my sisters and brother-in-law for putting up with me over the last 7 years and my nieces, Ella and Lucy, for diverting my attention from the research from time to time
- Zippy Dog for companionship and some degree of understanding

and

- finally, my partner Nikki for being so long suffering, providing loving support, conducting multiple lengthy reviews of the thesis (with interesting scientific insights) and without whom I could not have finished

Table of Contents

List of Figures

List of Figures

List of Tables

List of Tables

List of Acronyms

AC – Asbestos Cement Pipe

ARMA – Auto-Regressive Moving Average Error Model

AVFP – Air Valve/Fire Plug

BBM – Balmashanner Branch Main

BSOLVER – Explicit 1-D Method of Characteristics Transient Solver

CCE – Complex Evolution Algorithm

CCTV – Closed Circuit Television

CH – Chainage

CI – Cast Iron Pipe

CICL – Cast Iron Cement Mortar Lined Pipe

DI – Ductile Iron Pipe

DICL – Ductile Iron Cement Mortar Lined Pipe

DGCM – Discrete Gas Cavity Model (for discrete air pockets and entrained air)

DGCUF – Discrete Gas Cavity with Unsteady Friction Calibration Model

DWI – Drinking Water Inspectorate, United Kingdom

EPA – Environment Protection Agency, South Australia

ESTM – Essex to Suffolk Transmission Main

FSI – Fluid Structure Interaction

FSP – Foster Street Distribution Pipeline

FTM – Forward Transient Model

GA – Genetic Algorithm

GASB – Governmental Accounting Standards Board, USA

GPS – Global Positioning Survey

HDPE – High Density Polyethylene Pipe

HTP – Hanson Transmission Pipeline

ID – Internal Diameter

ITA – Inverse Transient Analysis

KCP – Kookaburra Court Distribution Pipeline

MOC – Method of Characteristics

MS – Mild Steel Pipe

MSCL – Mild Steel Cement Mortar Lined Pipe

MTP – Morgan Transmission Pipeline

NETTRANS – Implicit 1-D Method of Characteristics Transient Network Solver

NE Valve – North Eastern In-line Gate Valve in Willunga Network

NLFIT – Non-Linear Regression Program Suite by Professor George Kuczera

OF or O/F – Objective Function following Least Squares Minimisation

OFWAT – Office of Water Service, United Kingdom

PDCR-810 – Druck Pressure Transducer

PRBS – Psuedo Random Binary Signal

QSF – Quasi-Steady Friction Calibration Model

SAHARA – Proprietary Acoustic Leak Detection System

SCE – Shuffled Complex Evolution Search Algorithm

SCE-UA – Shuffled Complex Evolution Search Algorithm – University of Arizona

SE Valve – South Eastern In-line Gate Valve in Willunga Network

SJTP – Saint Johns Terrace Distribution Pipeline

SW Valve – South Western In-line Gate Valve in Willunga Network

SZVCM – Spatially Zoned "Viscous" Mechanical Damping Calibration Model

UF – Unsteady Friction Calibration Model

UFVHOB – Unsteady Friction and "Viscous" Mechanical Damping Hanson Pipeline and Offtake Branch Calibration Model

uPVC – Non-Plasticised Polyvinyl Chloride Pipe

USEPA – United States Environment Protection Agency

Use of word "inelastic" in Chapter 16 equates to "viscous" elsewhere in thesis

WT127 – Voltage Signal Amplifier