



UNIVERSIDADE ESTADUAL DE CAMPINAS

Faculdade de Engenharia Mecânica

Felipe de Castro Teixeira Carvalho

Characterization of two-phase vertical flow in pipes using flow-induced vibration

Caracterização de escoamentos bifásicos verticais em tubulação utilizando vibração induzida por escoamentos

CAMPINAS
2018

Felipe de Castro Teixeira Carvalho

Characterization of two-phase vertical flow in pipes using flow-induced vibration

Caracterização de escoamentos bifásicos verticais em tubulação utilizando vibração induzida por escoamentos

Dissertation presented to the School of Mechanical Engineering of the University of Campinas in partial fulfillment of the requirements for the degree of Master in Mechanical Engineering, in the area of Mechatronics.

Dissertação apresentada à Faculdade de Engenharia Mecânica da Universidade Estadual de Campinas como parte dos requisitos exigidos para obtenção do título de Mestre em Engenharia Mecânica, na Área de Mecatrônica.

Orientador: Prof. Dr. Alberto Luiz Serpa

ESTE EXEMPLAR CORRESPONDE À
VERSÃO FINAL DA DISSERTAÇÃO DE-
FENDIDA PELO ALUNO FELIPE DE
CASTRO TEIXEIRA CARVALHO, E ORI-
ENTADO PELO PROF. DR. ALBERTO
LUIZ SERPA.

CAMPINAS
2018

Ficha catalográfica

Universidade Estadual de Campinas
Biblioteca da Área de Engenharia e Arquitetura
Luciana Pietrosanto Milla - CRB 8/8129

Carvalho, Felipe de Castro Teixeira, 1993-
C253c Characterization of two-phase vertical flow in pipes using flow-induced vibration / Felipe de Castro Teixeira Carvalho. – Campinas, SP : [s.n.], 2018.

Orientador: Alberto Luiz Serpa.
Dissertação (mestrado) – Universidade Estadual de Campinas, Faculdade de Engenharia Mecânica.

1. Processamento de sinais. 2. Escoamento bifásico. 3. Escoamento multifásico. 4. Vibração. I. Serpa, Alberto Luiz, 1967-. II. Universidade Estadual de Campinas. Faculdade de Engenharia Mecânica. III. Título.

Informações para Biblioteca Digital

Título em outro idioma: Caracterização de escoamentos bifásicos verticais em tubulação utilizando vibração induzida por escoamentos

Palavras-chave em inglês:

Signal processing

Two-phase flow

Multiphase flow

Vibration

Área de concentração: Mecatrônica

Titulação: Mestre em Engenharia Mecânica

Banca examinadora:

Alberto Luiz Serpa [Orientador]

Oscar Maurício Hernandez Rodriguez

Tiago Henrique Machado

Data de defesa: 16-08-2018

Programa de Pós-Graduação: Engenharia Mecânica

UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ENGENHARIA MECÂNICA
COMISSÃO DE PÓS-GRADUAÇÃO EM ENGENHARIA
MECÂNICA
DEPARTAMENTO DE MECÂNICA COMPUTACIONAL
DISSERTAÇÃO DE MESTRADO ACADÊMICO

***Characterization of two-phase vertical flow in
pipes using flow-induced vibration***

***Caracterização de escoamentos bifásicos
verticais em tubulação utilizando vibração
induzida por escoamento***

Autor: Felipe de Castro Teixeira Carvalho

Orientador: Prof. Dr. Alberto Luiz Serpa

A Banca Examinadora composta pelos membros abaixo aprovou esta Dissertação:

Prof. Dr. Alberto Luiz Serpa, Presidente
DMC/FEM/UNICAMP

Prof. Dr. Oscar Maurício Hernandez Rodriguez
SEM/EESC/USP

Prof. Dr. Tiago Henrique Machado
DSI/FEM/UNICAMP

A Ata da defesa com as respectivas assinaturas dos membros encontra-se no processo de vida acadêmica do aluno.

Campinas, 16 de Agosto de 2018.

Dedication

This dissertation is dedicated to my parents.

Acknowledgement

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vel congue lorem, nec aliquam ex. Nulla quis dui vel eros volutpat viverra a vitae odio. Maecenas non venenatis augue. Mauris eros est, lacinia sit amet rhoncus vel, molestie et dolor. Donec sapien lectus, dignissim a tellus mattis, dignissim varius lectus. In venenatis nibh turpis, sit amet porttitor elit dictum non. In in dictum leo. Suspendisse vestibulum nunc augue, ac bibendum risus hendrerit ac. In dui turpis, ultrices vitae pulvinar ac, maximus nec justo. Morbi tincidunt, nunc sit amet facilisis luctus, nunc sem lobortis erat, sit amet ornare orci tortor ut ex. Curabitur ut lacus dui.

Donec ipsum sem, ultrices et tristique eget, fringilla in enim. Ut id varius tellus, sit amet rhoncus nulla. Fusce lacinia enim eget mi elementum fringilla. Nulla facilisi. Aenean vitae urna porta ipsum tempor lacinia quis id ligula. Nam lobortis neque nec arcu convallis laoreet. Orci varius natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Morbi tempus molestie purus vitae pharetra. Donec interdum lacus neque, a scelerisque nisl pharetra at. Curabitur a iaculis odio. Interdum et malesuada fames ac ante ipsum primis in faucibus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Sed vulputate augue a urna ullamcorper egestas. Maecenas ligula lectus, porta non facilisis eget, finibus vel nisi. Ut finibus sollicitudin nisl, ut lacinia enim consequat sed.

Integer eget tempor velit. Duis rhoncus ligula id nunc rutrum gravida. Phasellus at imperdiet neque. Praesent fringilla a nibh ac egestas. Mauris vel porttitor elit, quis faucibus erat. Ut viverra justo id nisl gravida, quis tristique leo venenatis. Donec magna neque, maximus vel convallis eu, consequat lobortis orci. Pellentesque placerat enim vitae arcu malesuada, nec convallis eros dapibus. Aenean vitae mi volutpat, mattis lorem sit amet, ultricies magna. Integer convallis congue quam, eget maximus turpis blandit eget. Nullam lorem quam, condimentum quis eleifend eget, ultricies ac eros. Sed porttitor molestie ante a scelerisque. Aliquam erat volutpat. Duis arcu elit, laoreet consequat sapien eget, suscipit scelerisque magna. Praesent leo justo, scelerisque eget rutrum id, faucibus in dui. Maecenas a dolor id elit condimentum mattis nec id turpis.

Let us strive for the impossible. The great achievements throughout history have been the conquest of what seemed the impossible.

Charlie Chaplin

Resumo

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vel congue lorem, nec aliquam ex. Nulla quis dui vel eros volutpat viverra a vitae odio. Maecenas non venenatis augue. Mauris eros est, lacinia sit amet rhoncus vel, molestie et dolor. Donec sapien lectus, dignissim a tellus mattis, dignissim varius lectus. In venenatis nibh turpis, sit amet porttitor elit dictum non. In in dictum leo. Suspendisse vestibulum nunc augue, ac bibendum risus hendrerit ac. In dui turpis, ultrices vitae pulvinar ac, maximus nec justo. Morbi tincidunt, nunc sit amet facilisis luctus, nunc sem lobortis erat, sit amet ornare orci tortor ut ex. Curabitur ut lacus dui.

Donec ipsum sem, ultrices et tristique eget, fringilla in enim. Ut id varius tellus, sit amet rhoncus nulla. Fusce lacinia enim eget mi elementum fringilla. Nulla facilisi. Aenean vitae urna porta ipsum tempor lacinia quis id ligula. Nam lobortis neque nec arcu convallis laoreet. Orci varius natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Morbi tempus molestie purus vitae pharetra. Donec interdum lacus neque, a scelerisque nisl pharetra at. Curabitur a iaculis odio. Interdum et malesuada fames ac ante ipsum primis in faucibus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Sed vulputate augue a urna ullamcorper egestas. Maecenas ligula lectus, porta non facilisis eget, finibus vel nisi. Ut finibus sollicitudin nisl, ut lacinia enim consequat sed.

Integer eget tempor velit. Duis rhoncus ligula id nunc rutrum gravida. Phasellus at imperdiet neque. Praesent fringilla a nibh ac egestas. Mauris vel porttitor elit, quis faucibus erat. Ut viverra justo id nisl gravida, quis tristique leo venenatis. Donec magna neque, maximus vel convallis eu, consequat lobortis orci. Pellentesque placerat enim vitae arcu malesuada, nec convallis eros dapibus. Aenean vitae mi volutpat, mattis lorem sit amet, ultricies magna. Integer convallis congue quam, eget maximus turpis blandit eget. Nullam lorem quam, condimentum quis eleifend eget, ultricies ac eros. Sed porttitor molestie ante a scelerisque. Aliquam erat volutpat. Duis arcu elit, laoreet consequat sapien eget, suscipit scelerisque magna. Praesent leo justo, scelerisque eget rutrum id, faucibus in dui. Maecenas a dolor id elit condimentum mattis nec id turpis.

Palavras-chave: L^AT_EX; Modelo; Faculdade de Engenharia Mecânica; UNICAMP.

Abstract

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vel congue lorem, nec aliquam ex. Nulla quis dui vel eros volutpat viverra a vitae odio. Maecenas non venenatis augue. Mauris eros est, lacinia sit amet rhoncus vel, molestie et dolor. Donec sapien lectus, dignissim a tellus mattis, dignissim varius lectus. In venenatis nibh turpis, sit amet porttitor elit dictum non. In in dictum leo. Suspendisse vestibulum nunc augue, ac bibendum risus hendrerit ac. In dui turpis, ultrices vitae pulvinar ac, maximus nec justo. Morbi tincidunt, nunc sit amet facilisis luctus, nunc sem lobortis erat, sit amet ornare orci tortor ut ex. Curabitur ut lacus dui.

Donec ipsum sem, ultrices et tristique eget, fringilla in enim. Ut id varius tellus, sit amet rhoncus nulla. Fusce lacinia enim eget mi elementum fringilla. Nulla facilisi. Aenean vitae urna porta ipsum tempor lacinia quis id ligula. Nam lobortis neque nec arcu convallis laoreet. Orci varius natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Morbi tempus molestie purus vitae pharetra. Donec interdum lacus neque, a scelerisque nisl pharetra at. Curabitur a iaculis odio. Interdum et malesuada fames ac ante ipsum primis in faucibus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Sed vulputate augue a urna ullamcorper egestas. Maecenas ligula lectus, porta non facilisis eget, finibus vel nisi. Ut finibus sollicitudin nisl, ut lacinia enim consequat sed.

Integer eget tempor velit. Duis rhoncus ligula id nunc rutrum gravida. Phasellus at imperdiet neque. Praesent fringilla a nibh ac egestas. Mauris vel porttitor elit, quis faucibus erat. Ut viverra justo id nisl gravida, quis tristique leo venenatis. Donec magna neque, maximus vel convallis eu, consequat lobortis orci. Pellentesque placerat enim vitae arcu malesuada, nec convallis eros dapibus. Aenean vitae mi volutpat, mattis lorem sit amet, ultricies magna. Integer convallis congue quam, eget maximus turpis blandit eget. Nullam lorem quam, condimentum quis eleifend eget, ultricies ac eros. Sed porttitor molestie ante a scelerisque. Aliquam erat volutpat. Duis arcu elit, laoreet consequat sapien eget, suscipit scelerisque magna. Praesent leo justo, scelerisque eget rutrum id, faucibus in dui. Maecenas a dolor id elit condimentum mattis nec id turpis.

Keywords: L^AT_EX; Template; School of Mechanical Engineering; UNICAMP.

List of Figures

2.1	Minion	18
3.1	FEM	21
3.2	Experimental procedure flowchart.	22
3.3	Test matrix.	23

List of Tables

3.1 Liquid line components.	20
-------------------------------------	----

Nomenclature

Roman Symbols

F complex function

Greek Symbols

γ a simply closed curve on a complex plane

i unit imaginary number $\sqrt{-1}$

$\pi \simeq 3.14 \dots$

Superscripts

j superscript index

Subscripts

0 subscript index

crit Critical state

Other Symbols

\oint_{γ} integration around a curve γ

Acronyms / Abbreviations

ALU Arithmetic Logic Unit

BEM Boundary Element Method

CD Contact Dynamics

CFD Computational Fluid Dynamics

CIF Cauchy's Integral Formula

CK Carman - Kozeny

DEM Discrete Element Method

DKT Draft Kiss Tumble

DNS Direct Numerical Simulation

EFG Element-Free Galerkin
FEM Finite Element Method
FLOP Floating Point Operations
FPU Floating Point Unit
FVM Finite Volume Method
GPU Graphics Processing Unit
LBM Lattice Boltzmann Method
LES Large Eddy Simulation
MPM Material Point Method
MRT Multi-Relaxation Time
PCI Peripheral Component Interconnect
PFEM Particle Finite Element Method
PIC Particle-in-cell
PPC Particles per cell
RVE Representative Elemental Volume
SH Savage Hutter
SM Streaming Multiprocessors
USF Update Stress First
USL Update Stress Last

Contents

List of Figures	10
List of Tables	11
Nomenclature	12
Contents	14
1 Introduction	15
1.1 What is lorem ipsum?	15
1.2 Why do we use lorem ipsum?	15
1.3 Where does it come from?	15
2 Literature review	18
2.1 Short title	18
2.2 Enumeration	18
2.3 Itemize	19
3 Experimental apparatus and tests procedures	20
3.1 Experimental assembly	20
3.2 Experimental procedure	21
3.3 Test matrix	22
Bibliography	24
Appendix A Python codes	25
A.1 Animation example	25

1 Introduction

1.1 What is loren ipsum?

Lorem Ipsum is simply dummy text of the printing and typesetting industry (see Section ??). Lorem Ipsum [Aup91] has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like Aldus Page-Maker including versions of Lorem Ipsum [AAB95, Con90, LM65].

The most famous equation in the world: $E^2 = (m_0c^2)^2 + (pc)^2$, which is known as the **energy-mass-momentum** relation as an in-line equation.

A *LATEX class file* is a file, which holds style information for a particular LATEX.

$$CIF : \quad F_0^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(z)}{z - a} dz \quad (1.1)$$

1.2 Why do we use loren ipsum?

It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout. The point of using Lorem Ipsum is that it has a more-or-less normal distribution of letters, as opposed to using ‘Content here, content here’, making it look like readable English. Many desktop publishing packages and web page editors now use Lorem Ipsum as their default model text, and a search for ‘lorem ipsum’ will uncover many web sites still in their infancy. Various versions have evolved over the years, sometimes by accident, sometimes on purpose (injected humour and the like).

1.3 Where does it come from?

Contrary to popular belief, Lorem Ipsum is not simply random text. It has roots in a piece of classical Latin literature from 45 BC, making it over 2000 years old. Richard McClintock, a Latin professor at Hampden-Sydney College in Virginia, looked up one of the more obscure Latin words, *consectetur*, from a Lorem Ipsum passage, and going through the cites of the word in classical literature, discovered the undoubtable source. Lorem Ipsum comes from sections

1.10.32 and 1.10.33 of "de Finibus Bonorum et Malorum" (The Extremes of Good and Evil) by Cicero, written in 45 BC. This book is a treatise on the theory of ethics, very popular during the Renaissance [1, 2, 3, 4]. The first line of Lorem Ipsum, "Lorem ipsum dolor sit amet..", comes from a line in section 1.10.32.

According to Ortiz-Vidal, Mureithi and Rodriguez [5], the standard chunk of Lorem Ipsum used since the 1500s is reproduced below for those interested. Sections 1.10.32 and 1.10.33 from "de Finibus Bonorum et Malorum" by Cicero are also reproduced in their exact original form, accompanied by English versions from the 1914 translation by H. Rackham

"Lorem ipsum dolor siamet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum."

Section 1.10.32 of "de Finibus Bonorum et Malorum", written by Cicero in 45 BC: "Sed ut perspiciatis unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt explicabo. Nemo enim ipsam voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit amet, consectetur, adipisci velit, sed quia non numquam eius modi tempora incident ut labore et dolore magnam aliquam quaerat voluptatem. Ut enim ad minima veniam, quis nostrum exercitationem ullam corporis suscipit laboriosam, nisi ut aliquid ex ea commodi consequatur? Quis autem vel eum iure reprehenderit qui in ea voluptate velit esse quam nihil molestiae consequatur, vel illum qui dolorem eum fugiat quo voluptas nulla pariatur?"

1914 translation by H. Rackham: "But I must explain to you how all this mistaken idea of denouncing pleasure and praising pain was born and I will give you a complete account of the system, and expound the actual teachings of the great explorer of the truth, the master-builder of human happiness. No one rejects, dislikes, or avoids pleasure itself, because it is pleasure, but because those who do not know how to pursue pleasure rationally encounter consequences that are extremely painful. Nor again is there anyone who loves or pursues or desires to obtain pain of itself, because it is pain, but because occasionally circumstances occur in which toil and pain can procure him some great pleasure. To take a trivial example, which of us ever undertakes laborious physical exercise, except to obtain some advantage from it? But who has any right to find fault with a man who chooses to enjoy a pleasure that has no annoying consequences, or one who avoids a pain that produces no resultant pleasure?"

1914 translation by H. Rackham: "On the other hand, we denounce with righteous indignation and dislike men who are so beguiled and demoralized by the charms of pleasure of the moment, so blinded by desire, that they cannot foresee the pain and trouble that are bound to ensue; and equal blame belongs to those who fail in their duty through weakness of will, which

is the same as saying through shrinking from toil and pain. These cases are perfectly simple and easy to distinguish. In a free hour, when our power of choice is untrammelled and when nothing prevents our being able to do what we like best, every pleasure is to be welcomed and every pain avoided. But in certain circumstances and owing to the claims of duty or the obligations of business it will frequently occur that pleasures have to be repudiated and annoyances accepted. The wise man therefore always holds in these matters to this principle of selection: he rejects pleasures to secure other greater pleasures, or else he endures pains to avoid worse pains."

2 Literature review

2.1 Reasonably long section title

I'm going to randomly include a picture Figure 2.1.

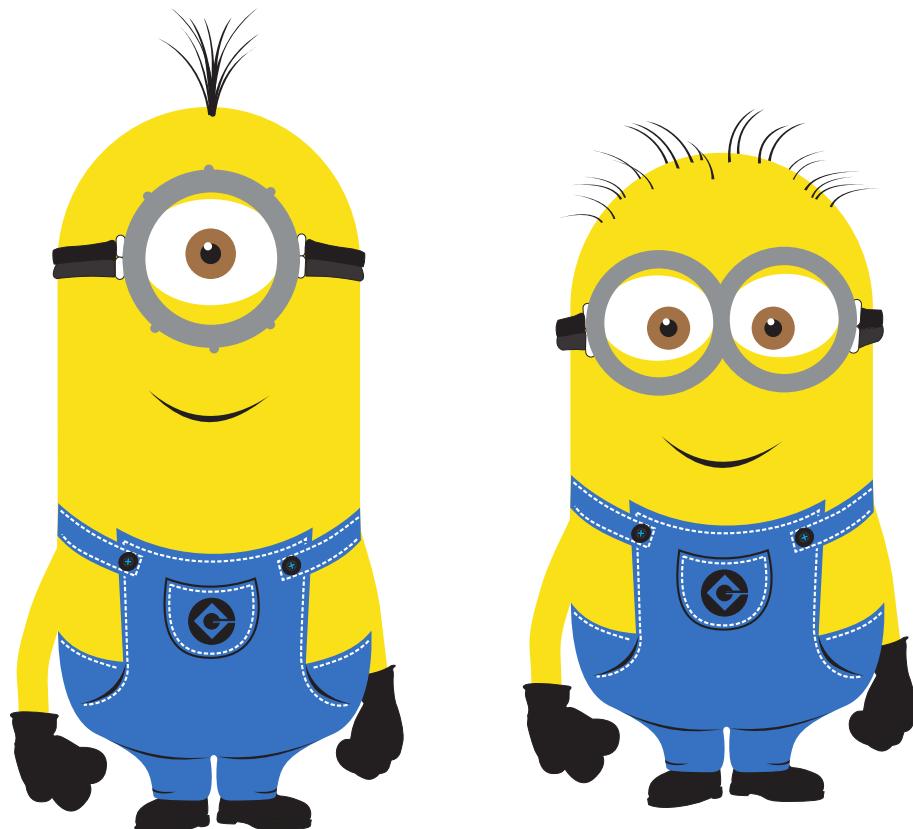


Figure 2.1: This is just a long figure caption for the minion in Despicable Me from Pixar

2.2 Enumeration

Loreum ipsum dolor sit amet, consectetur adipiscing elit. Sed vitae laoreet lectus. Donec lacus quam, malesuada ut erat vel, consectetur eleifend tellus. Aliquam non feugiat lacus. Interdum et malesuada fames ac ante ipsum primis in faucibus. Quisque a dolor sit amet dui malesuada malesuada id ac metus. Phasellus posuere egestas mauris, sed porta arcu vulputate ut. Donec arcu erat, ultrices et nisl ut, ultricies facilisis urna. Quisque iaculis, lorem non maximus pretium, dui eros auctor quam, sed sodales libero felis vel orci. Aliquam neque nunc, elementum id accumsan eu, varius eu enim. Aliquam blandit ante et ligula tempor pharetra. Donec molestie

porttitor commodo. Integer rutrum turpis ac erat tristique cursus. Sed venenatis urna vel tempus venenatis. Nam eu rhoncus eros, et condimentum elit. Quisque risus turpis, aliquam eget euismod id, gravida in odio. Nunc elementum nibh risus, ut faucibus mauris molestie eu.

Vivamus quis nunc nec nisl vulputate fringilla. Duis tempus libero ac justo laoreet tincidunt. Fusce sagittis gravida magna, pharetra venenatis mauris semper at. Nullam eleifend felis a elementum sagittis. In vel turpis eu metus euismod tempus eget sit amet tortor. Donec eu rhoncus libero, quis iaculis lectus. Aliquam erat volutpat. Proin id ullamcorper tortor. Fusce vestibulum a enim non volutpat. Nam ut interdum nulla. Proin lacinia felis malesuada arcu aliquet fringilla. Aliquam condimentum, tellus eget maximus porttitor, quam sem luctus massa, eu fermentum arcu diam ac massa. Praesent ut quam id leo molestie rhoncus. Praesent nec odio eget turpis bibendum eleifend non sit amet mi. Curabitur placerat finibus velit, eu ultricies risus imperdiet ut. Suspendisse lorem orci, luctus porta eros a, commodo maximus nisi.

1. The first topic is dull
2. The second topic is duller
 - (a) The first subtopic is silly
 - (b) The second subtopic is stupid
3. The third topic is the dullest

Morbi bibendum est aliquam, hendrerit dolor ac, pretium sem. Nunc molestie, dui in euismod finibus, nunc enim viverra enim, eu mattis mi metus id libero. Cras sed accumsan justo, ut volutpat ipsum. Nam faucibus auctor molestie. Morbi sit amet eros a justo pretium aliquet. Maecenas tempor risus sit amet tincidunt tincidunt. Curabitur dapibus gravida gravida. Vivamus porta ullamcorper nisi eu molestie. Ut pretium nisl eu facilisis tempor. Nulla rutrum tincidunt justo, id placerat lacus laoreet et. Sed cursus lobortis vehicula. Donec sed tortor et est cursus pellentesque sit amet sed velit. Proin efficitur posuere felis, porta auctor nunc. Etiam non porta risus. Pellentesque lacinia eros at ante iaculis, sed aliquet ipsum volutpat. Suspendisse potenti.

2.3 Itemize

- The first topic is dull
- The second topic is duller
 - The first subtopic is silly
 - The second subtopic is stupid
- The third topic is the dullest

3 Experimental apparatus and tests procedures

3.1 Experimental assembly

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vel congue lorem, nec aliquam ex. Nulla quis dui vel eros volutpat viverra a vitae odio. Maecenas non venenatis augue. Mauris eros est, lacinia sit amet rhoncus vel, molestie et dolor. Donec sapien lectus, dignissim a tellus mattis, dignissim varius lectus. In venenatis nibh turpis, sit amet porttitor elit dictum non. In in dictum leo. Suspendisse vestibulum nunc augue, ac bibendum risus hendrerit ac. In dui turpis, ultrices vitae pulvinar ac, maximus nec justo. Morbi tincidunt, nunc sit amet facilisis luctus, nunc sem lobortis erat, sit amet ornare orci tortor ut ex. Curabitur ut lacus dui.

Donec ipsum sem, ultrices et tristique eget, fringilla in enim. Ut id varius tellus, sit amet rhoncus nulla. Fusce lacinia enim eget mi elementum fringilla. Nulla facilisi. Aenean vitae urna porta ipsum tempor lacinia quis id ligula. Nam lobortis neque nec arcu convallis laoreet. Orci varius natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique Table 3.1 senectus et netus et malesuada fames ac turpis egestas.

Table 3.1: Liquid line components.

Name	Component	Manufacturer	Characteristics
SY-101	Motor	WEG	Three phase AC 220/380/440 V; 59.8/34.6/29.9 A; 18.5 HP; 1165 RPM
	Variable-frequency drive	WEG	Model CFW090030T; Three phase AC 380/480 V
FT-101	Cavity pump	Netzsch	Model NM053; 10 m ³ h to 21 m ³ h
	Coriolis flow-meter	Metroval	Model RHM40 - 3FS1PN

Integer eget tempor velit. Duis rhoncus ligula id nunc rutrum gravida. Phasellus at imperdiet neque. Praesent fringilla a nibh ac egestas. Mauris vel porttitor elit, quis faucibus erat. Ut viverra justo id nisl gravida, quis tristique leo venenatis. Donec magna neque, maximus vel convallis eu, consequat lobortis orci. Pellentesque placerat enim vitae arcu malesuada, nec convallis eros dapibus. Aenean vitae mi volutpat, mattis lorem sit amet, ultricies magna. Integer convallis congue quam, eget maximus turpis blandit eget. Nullam lorem quam, condimentum quis eleifend eget, ultricies ac eros. Sed porttitor molestie ante a scelerisque. Aliquam erat volutpat. Duis arcu elit, laoreet consequat sapien eget, suscipit scelerisque magna. Praesent leo justo, Figure 3.1 scelerisque eget rutrum id, faucibus in dui.



Figure 3.1: FEM with notes in the photo.

3.2 Experimental procedure

Integer eget tempor velit. Duis rhoncus ligula id nunc rutrum gravida. Phasellus at imperdiet neque. Praesent fringilla a nibh ac egestas. Mauris vel porttitor elit, quis faucibus erat. Ut viverra justo id nisl gravida, quis tristique leo venenatis. Donec magna neque, maximus vel convallis eu, consequat lobortis orci. Pellentesque placerat enim vitae arcu malesuada, nec convallis eros dapibus. Aenean vitae mi volutpat, mattis lorem sit amet, ultricies magna.

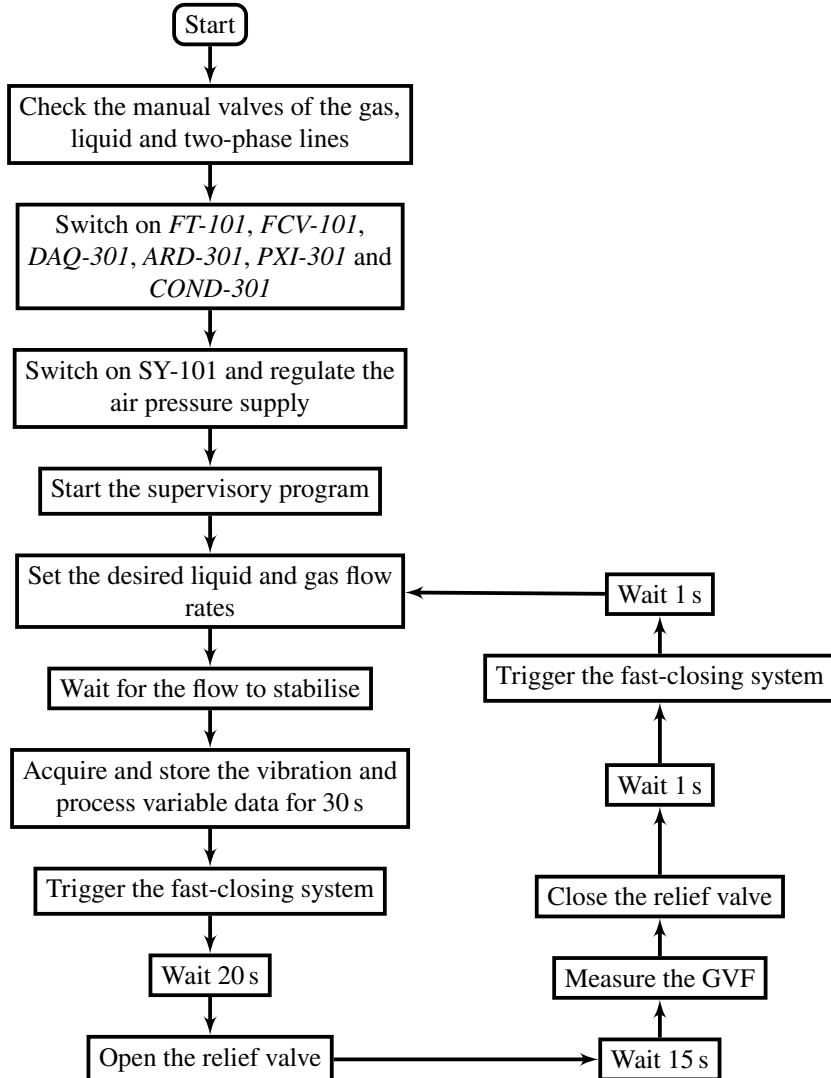


Figure 3.2: Experimental procedure flowchart.

3.3 Test matrix

Integer convallis congue quam, eget maximus turpis blandit eget. Nullam lorem quam, condimentum quis eleifend eget, ultricies ac eros. Sed porttitor molestie ante a scelerisque. Aliquam erat volutpat. Duis arcu elit, laoreet consequat sapien eget, suscipit scelerisque magna. Praesent leo justo, scelerisque eget rutrum id, faucibus in dui. Maecenas a dolor id elit condimentum mattis nec id turpis.

Nullam non justo cursus sapien porttitor malesuada vitae et diam. Ut sed imperdiet dolor, sed volutpat metus. Nam at est condimentum, consectetur tortor quis, accumsan lorem. Mauris vel ex eu purus pellentesque dictum. Morbi vulputate mollis elit. Vestibulum auctor diam eu ligula interdum finibus. In hac habitasse platea dictumst. Cras non ultricies metus. Aliquam eget nibh eget ex accumsan sagittis nec ac mauris. Suspendisse consectetur tellus quis purus porttitor, ac tincidunt urna dictum. In dictum neque quis lorem ullamcorper condimentum 3.3.

Donec interdum lacus neque, a scelerisque nisl pharetra at. Curabitur a iaculis odio. Inter-



Figure 3.3: Test matrix as function of the liquid and gas superficial velocities.

dum et malesuada fames ac ante ipsum primis in faucibus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Sed vulputate augue a urna ullamcorper egestas. Maecenas ligula lectus, porta non facilisis eget, finibus vel nisi. Ut finibus sollicitudin nisl, ut lacinia enim consequat sed.



(a) CEPETRO.



(b) LABPETRO.

Bibliography

- [1] M. Abdulkadir, V. Hernandez-Perez, L. Abdulkareem, I. S. Lowndes and B. J. Azzopardi, “Characteristics of slug flow in a vertical riser”, *34th SPE Annual International Conference and Exhibition*, vol. 2, pp. 875–881, 2010.
- [2] K. H. Bendiksen, “An experimental investigation of the motion of long bubbles in inclined tubes”, *International Journal of Multiphase Flow*, vol. 10, no. 4, pp. 467–483, 1984.
- [3] G. Falcone, “Chapter 7 Heavy Oil Metering Applications”, in *Multiphase Flow Metering*, ser. Developments in Petroleum Science, G. Falcone, G. F. Hewitt and C. Alimonti, Eds., vol. 54, Elsevier, 2009, pp. 251–266.
- [4] K. Fujita, “Flow-Induced Vibration and Fluid-Structure Interaction in Nuclear Power Plant Components”, *J. Wind Engineering and Industrial Aerodynamics*, vol. 33, no. 1, pp. 405–418, 1990.
- [5] L. E. Ortiz-Vidal, N. W. Mureithi and O. M. H. Rodriguez, “Vibration response of a pipe subjected to two-phase flow: Analytical formulations and experiments”, *Nuclear Engineering and Design*, vol. 313, pp. 214–224, 2017.

A Python codes

A.1 Animation example

```
1    """
2    =====
3    Random data
4    =====
5
6    An animation of random data.
7
8    """
9
10   import numpy as np
11   import matplotlib.pyplot as plt
12   import matplotlib.animation as animation
13
14   fig, ax = plt.subplots()
15   line, = ax.plot(np.random.rand(10))
16   ax.set_ylim(0, 1)
17
18
19   def update(data):
20       line.set_ydata(data)
21       return line,
22
23
24   def data_gen():
25       while True:
26           yield np.random.rand(10)
27
28   ani = animation.FuncAnimation(fig, update, data_gen, interval=100)
29   plt.show()
```
