



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

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

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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

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CASTRO TEIXEIRA CARVALHO, E ORI-
ENTADO PELO PROF. DR. ALBERTO
LUIZ SERPA.

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DISSERTAÇÃO DE MESTRADO ACADÊMICO

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induzida por escoamentos*

Autor: Felipe de Castro Teixeira Carvalho

Orientador: Prof. Dr. Alberto Luiz Serpa

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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

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

Charlie Chaplin

Resumo

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

Abstract

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

List of Figures

2.1	Minion	19
3.1	FEM	22
3.2	Experimental procedure flowchart.	23
3.3	Test matrix.	24

List of Tables

3.1 Liquid line components.	21
-------------------------------------	----

List of Symbols

List of Acronyms

Contents

List of Figures	10
List of Tables	11
Contents	14
1 Introduction	16
1.1 What is lorem ipsum?	16
1.2 Why do we use lorem ipsum?	16
1.3 Where does it come from?	16
2 Literature review	19
2.1 Short title	19
2.2 Enumeration	19
2.3 Itemize	20
3 Experimental apparatus and tests procedures	21
3.1 Experimental assembly	21
3.2 Experimental procedure	22
3.3 Test matrix	23
Bibliography	25
Appendix A Python codes	26
A.1 Animation example	26

ss

1 Introduction

1.1 What is lorem 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 PageMaker 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.

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

1.2 Why do we use lorem 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

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Section 1.10.32 of "de Finibus Bonorum et Malorum", written by Cicero in 45 BC: "Sed ut perspicatis 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."

Particle Finite Element Method Floating Point Operations Critical state

2 Literature review

2.1 Reasonably long section title

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

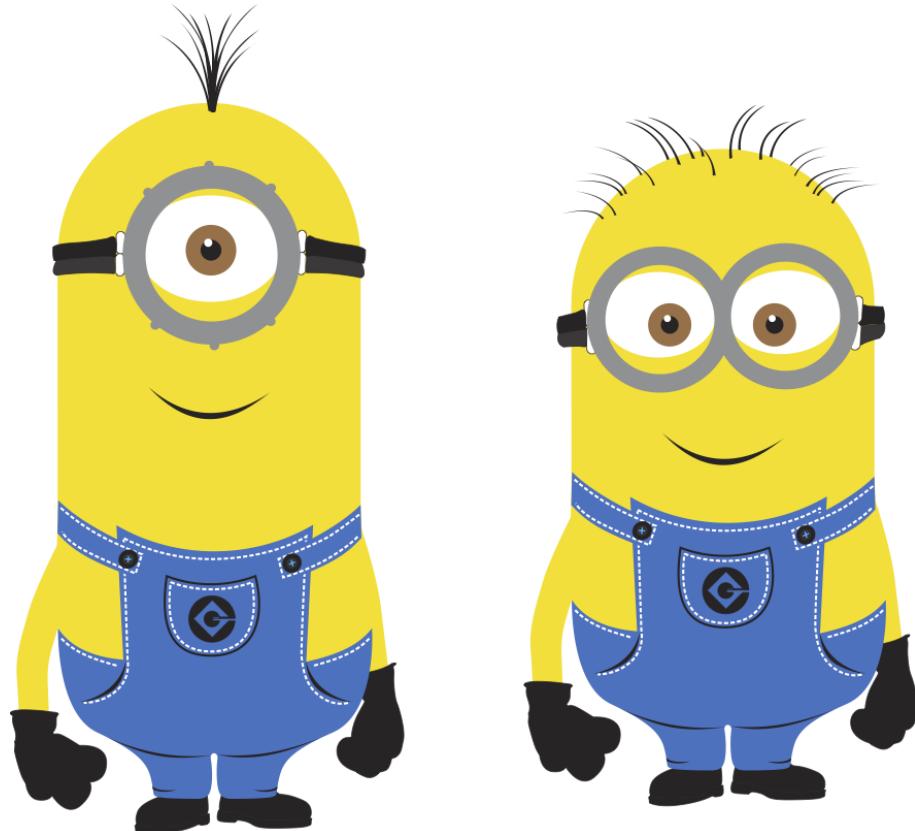


Figure 2.1: This is just a long figure caption for the minion in Despicable Me from Pixar

2.2 Enumeration

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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

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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

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Table 3.1: Liquid line components.

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

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Figure 3.1: FEM with notes in the photo.

3.2 Experimental procedure

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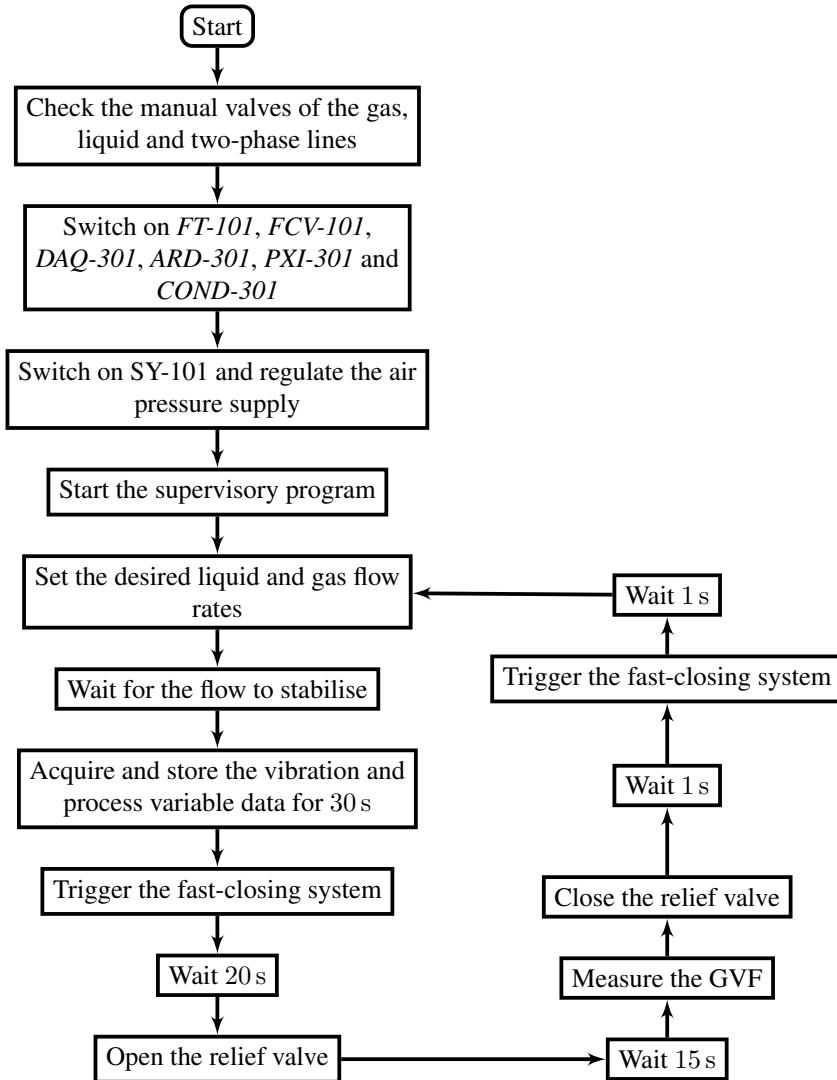


Figure 3.2: Experimental procedure flowchart.

3.3 Test matrix

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

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(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()
```
