On two-phase flow models for Coriolis flowmeters

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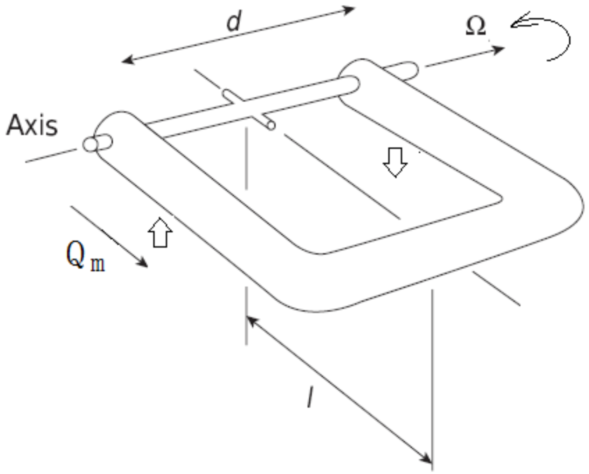
Contents

Introduction

- a Coriolis flowmeter measures flowrate by force.
- play as a ‘real’ mass flowmeter.
- multi-purpose measurement by one meter.



Based on Baker: Flow Measurement Handbook,2nd Ed. CUP

Errors of Coriolis flowmeters in multiphase flow
(Test data)

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Author	Coriolis meter installation	Fluids	Void fraction	Max. Error
Skea and Hall	Straight, Curved 3 others	Oil+N2 Water in oil, Oil in water	6% N_2 9% N_2 Max. 15%	-15% +5% 0.3%(small) Not work
Wang et al	Vertical Horizontal	Liquid and gas CO_2	0~70%	-16%~2% -4%~14%
Michael et al	normal	High viscous oil N_2	0~90%	±2% ±5%
Liu et al	U type	air, water	0~35%	0~-25%
B B Tao et al	U type, horizontal	Gas, water	0~25%	2%~-22%
Weinstein	U type, up/down	Gas, water	0~8%	Up: -15%, down: 12%

Models for Coriolis flowmeters in multiphase flow

- 2003 Hemp and Hoi: bubble model – solid sphere
- 2006 Hemp and Kutin: compressibility, well mixed
- 2007 Gysling: aeroelastic model
- 2008 Weistain Ph D thesis: phase decouple , relative speed
- 2014 Wang and Baker: detailed Review of Coriolis flowmeter
- 2016 Basse: damping

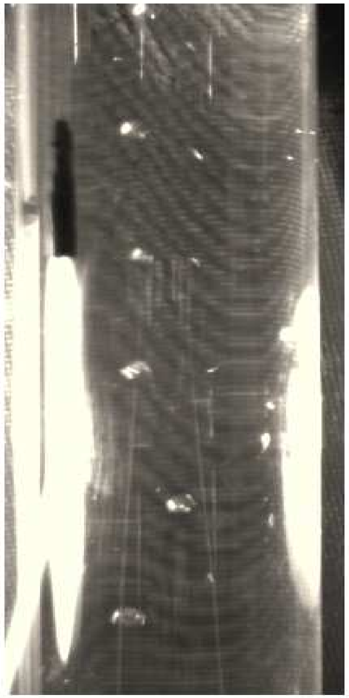
- 2001 Liu at el: neural network for signal

But works still being done to improve the models

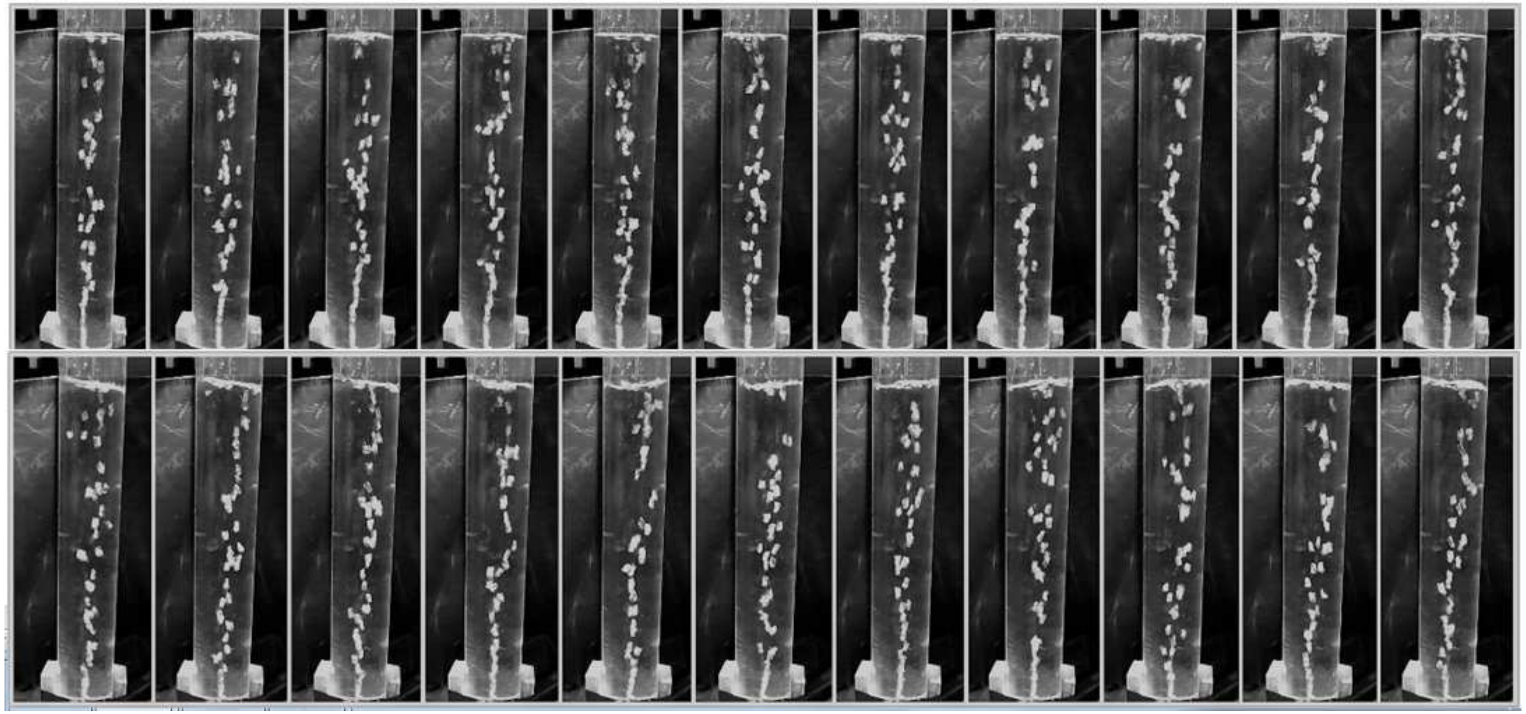
we were trying to look at how multiphase flows affect a Coriolis flowmeter

Experiment -1： Bubble rising in still water

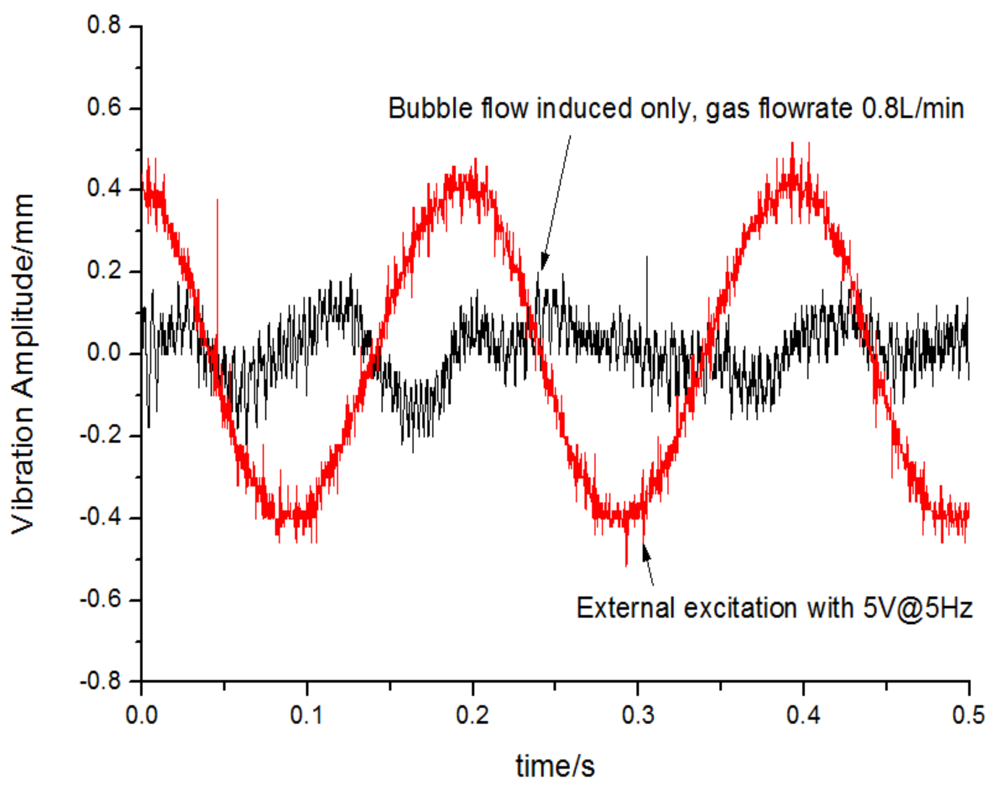
- Bubble shape - flexible flat instead of solid sphere
  shape changes while moving



- Bubble motion – spiral instead of straight, caused by flat bubble shape



• bubble induced vibration



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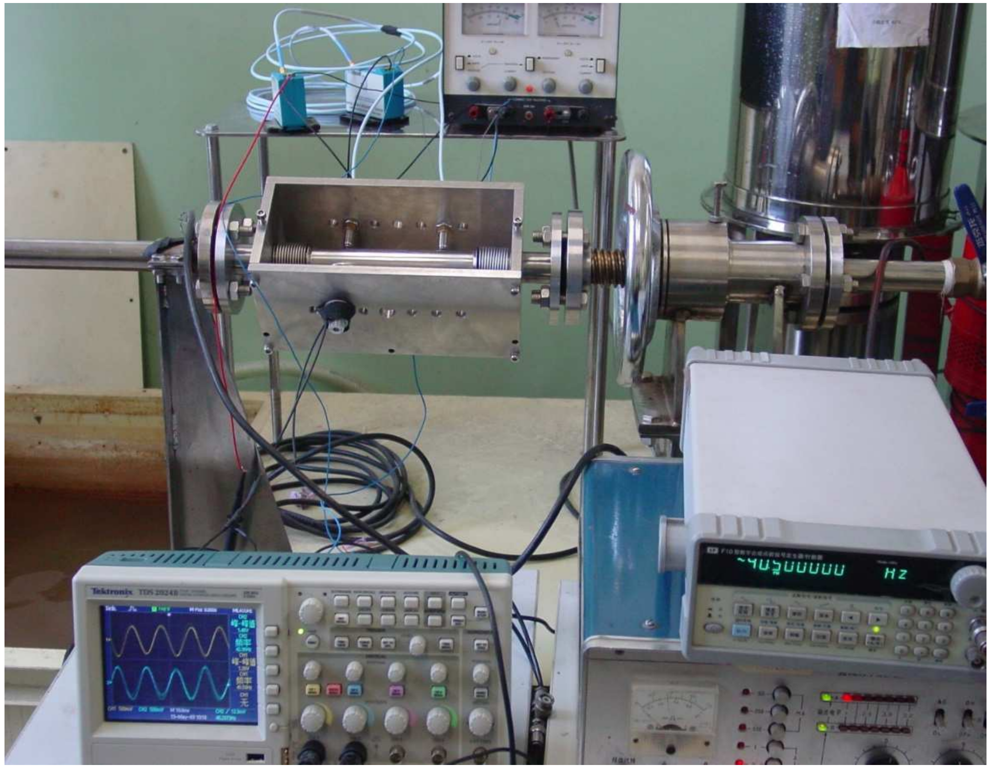
- Standard deviation of bubble flow induced vibration

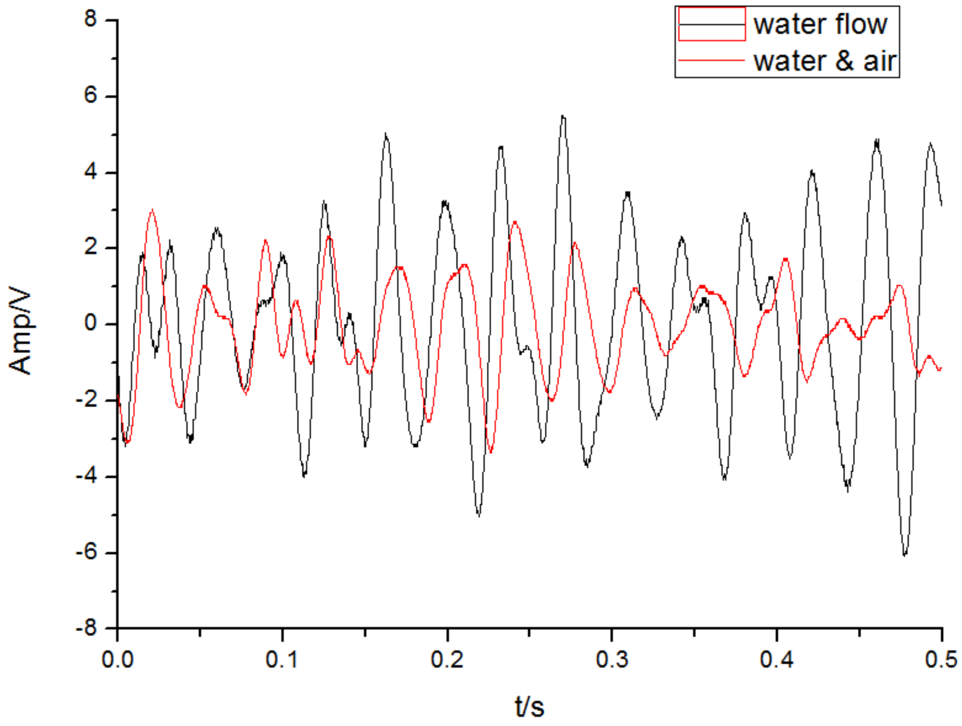
Gas flowrate(L/min)	0.4	0.8	1.2	1.6
Standard deviation with uncertainty	0.053 ±0.003	0.083 ±0.002	0.148 ±0.035	0.235 ±0.067

induced vibration increases with gas void fraction

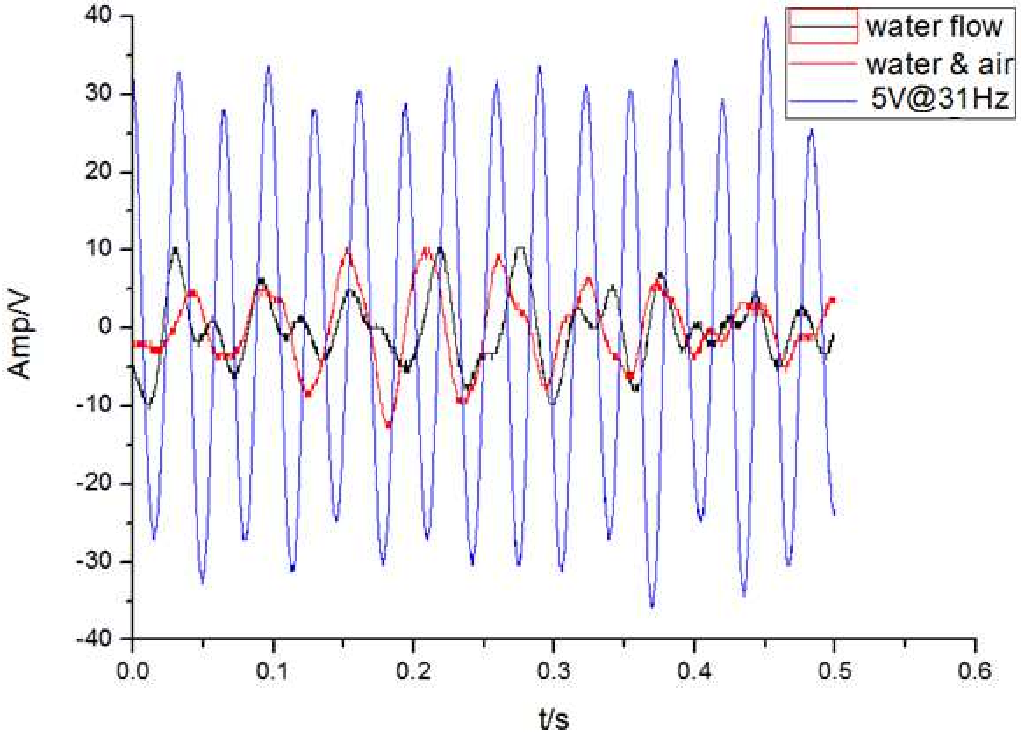
Experiment - 2: water-air flows



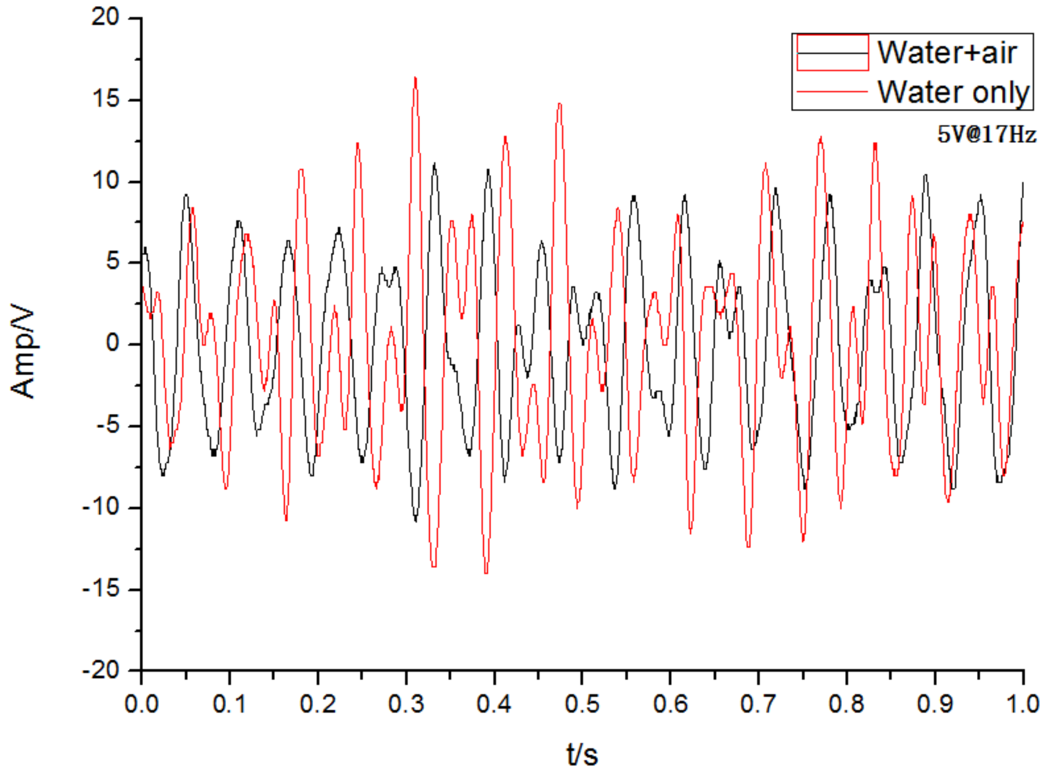
- Flows induced vibration



- water flow with/without external vibration



water flow and water- air flow under external excitation



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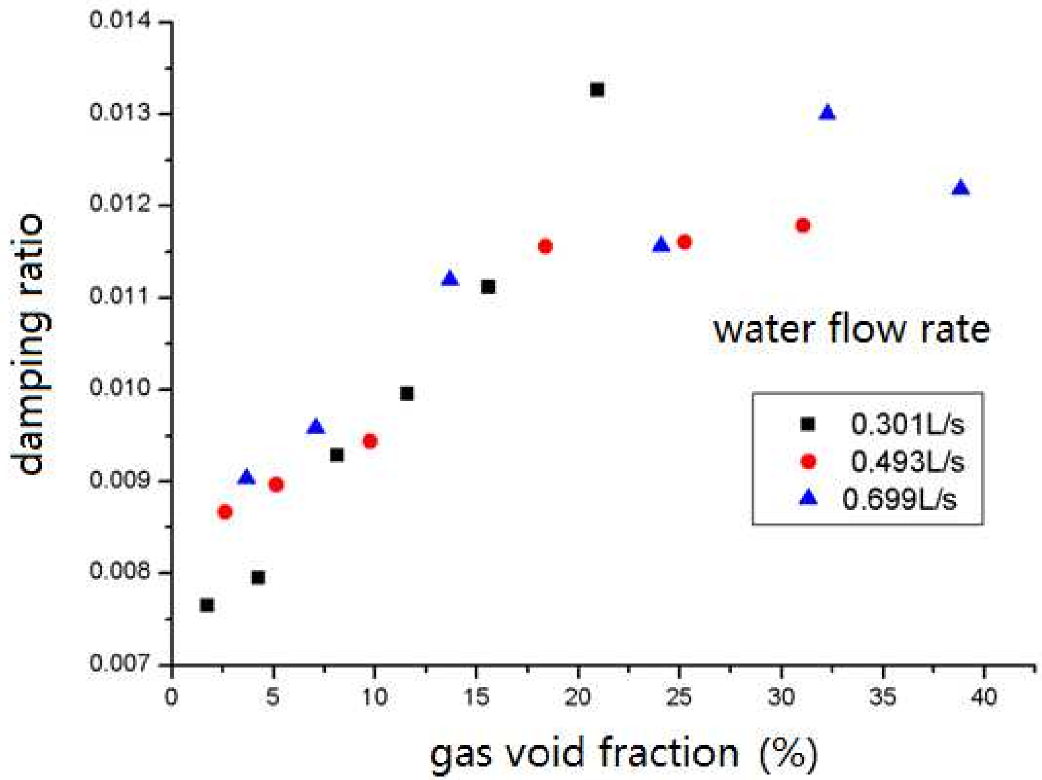
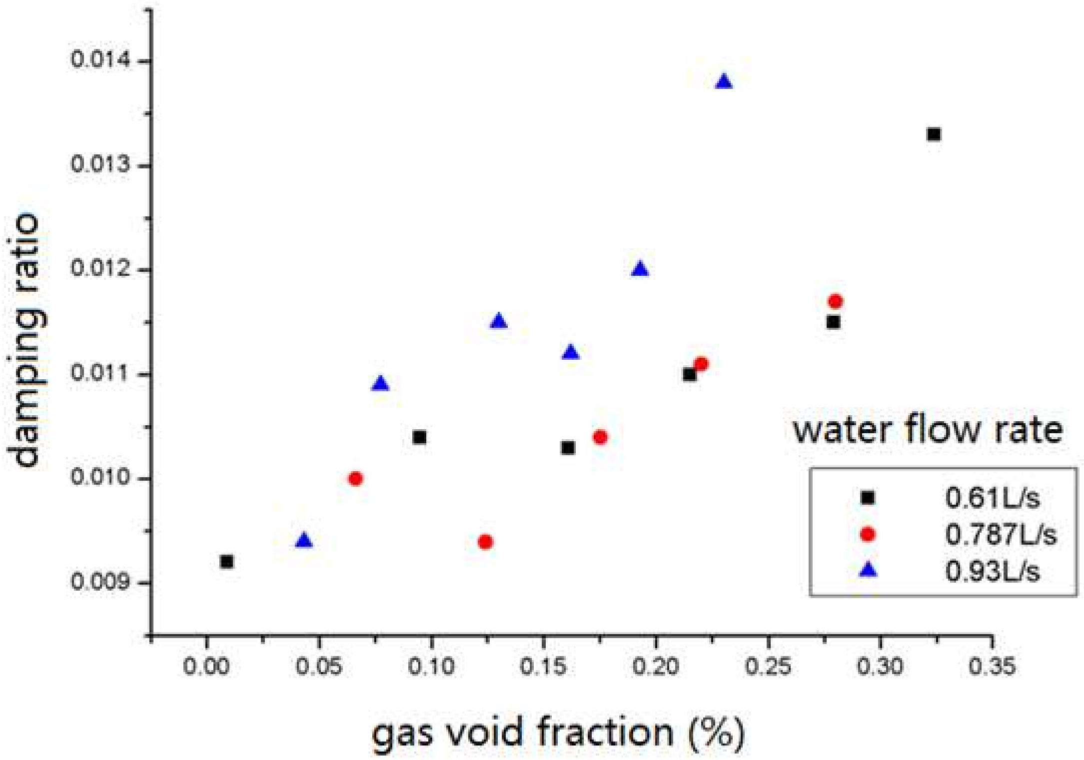
- Water-air flow under vibration – 1st modal damping



- Damping -2nd modal



In modeling

- Transverse vibration of a Coriolis flowmeter in water-air flow may be described by this simplified equation:

$$M\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx = F_0\sin(\omega t) + F_1 + F_2$$

M - total mass including water and 'added mass' of air;

C - total damping including structure, fluids, phase interaction

K – structure stiffness mainly

$F_0 \sin(\omega t)$ - external excitation

F_1 – Coriolis force

F_2 – water+ air flows induced transverse force

- almost known   - known to some extent   - hard to predict

Bubble shape

- Relative motion/'decouple' makes bubble shape changes. Solid sphere bubble model seems not real. 'Added mass' depends on the shape.
- A flat bubble with added mass coefficient can be up to 0.97. It is larger than 0.5 as given to sphere bubble.
- Unable to give a correct 'added mas's causes error of models.

Damping of flow

- Existence of bubbles in water causes extra vibration damping.
- The damping ratio is proportional to void fraction of the air for both vibration modals (1st and 2nd)
- Damping suppresses vibration amplitude especially near resonance region, and makes a small shift of resonance frequency.
- Unknown damping may cause error in flowrate measurement

Bubble motion

- Bubbles travel in non-straight way, this induces transverse vibration additional to external excitation, the later is applied by the flowmeter.
- The induced vibration may cause error in flowrate measurement

flowmeter structure

- Structure of the flowmeter has its intrinsic vibration response property. This is called transfer function.
- Flow induced vibration and external excitation will go through the transfer function to output signal.
- Poor structure design may amplify bubble induced vibration

Some thing missing?

- Phase distribution and bubble interaction are not considered in above equation.
- They are hard to measure and to describe mathematically.

Possible ways to do improvement

- With good understanding of principles of the meters in multiphase flow:

  Do numerical computation using commercial software for a better design.

- For existing meters:

  Do more measurements (induced vibration, multi-frequency excitation, additional sensors), then do signal analysis

further work to do

Summary

- We review works on theoretical models for Coriolis flowmeters used in multiphase flows
- We do experiments on bubble rising in still water and on water-air two-phase flow, with/without external vibration
- It is found:
  1) bubbles cannot be taken as solid spheres
  2) bubbles moving in water induce transverse vibration
  3) bubbles in water induce vibration damping

- Also, difficulties in giving a good model for a Coriolis flow meter in two-phase flow are discussed.
- Further work to improve the theoretical model to reduce measurement errors are suggested.

References

[1] Baker RC. Flow measurement handbook : Cambridge University Press; 2016

[2] Wang T, Baker RC, Coriolis flowmeters: a review of developments over the past 20 years, and an assessment of the state of the art and likely future directions, Flow Meas. Instrum. 40 (2014) 99–123.

[3] Hemp J and Yeung H. 2003. Coriolis meter in two phase condition, Computer and Control Engineering. 14:36-36.

[4] Hemp J, Kutin J. Theory of errors in Coriolis flowmeter readings due to compressibility of the fluid being metered. Flow Meas. Instrum. 2006;17:359–69.

[5] Weinstein JA, The Motion of Bubbles and Particles in Oscillating Liquids with Applications to Multiphase Flow in Coriolis Meters, University of Colorado, Boulder, Colorado, USA, 2008.

[6] Gysling D L， An aeroelastic model of Coriolis mass and density meters operating on aerated mixtures ， Flow. Meas. Instrum. 2007;18: 69-77.

[7] Liu RP, Fuent MJ, Henry MP, Duta MD. A neural network to correct mass flow errors caused by two-phase flow in a digital Coriolis mass flowmeter. Flow. Meas. Instrum. 2001;12:23–63.

[8] Basse NT. Coriolis flowmeter damping for two-phase flow due to decoupling， Flow. Meas. Instrum. 2016;52:40-52.

[9] Landau LD, Lifshitz EM. Fluid mechanics. 2nd ed. Pergamon Press; 1987

[10] Brennen C E: Fundamentals of Multiphase Flows, Cambridge University Press, 2005

[11] Charreton C et al: Two-phase damping for internal flow: Physical mechanism and effect of excitation parameters, J. Fluids and Structures, 56(2015);56-74

[12] Zhang XZ: Damping of vibrating pipe conveying water-air flow and its effect on Coriolis flow meter, SICE2016, Tsukuba, Japan

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