Predicting the Output Error of a Coriolis Flowmeter under Gas-Liquid Two-Phase Conditions through Analytical Modelling

Jinyu Liu$^{1,2}$, Tao Wang$^{1,2}$, Yong Yan$^{1,*}$, Xue Wang$^3$

$^1$School of Engineering and Digital Arts, University of Kent, Canterbury, Kent CT2 7NT, U.K.
$^2$KROHNE Ltd., Wellingborough NN8 6AE, U.K.
$^3$School of Mathematics, Statistics and Actuarial Science, University of Kent, Canterbury, Kent CT2 7FS, U.K.

* E-mail (corresponding author): Y.Yan@kent.ac.uk
Outline

• Introduction
• Methodology
• Experimental Work
• Data Interpretation
• Conclusions
Introduction

Gas-liquid two-phase flow

- Complex, liquid dominant flow (0-40% GVF)
- Unavoidable in many industrial processes
- Low uncertainty in overall measurement is required
Introduction

Typical application scenario

- 0.3% uncertainty under single-phase conditions
- 0.5% overall uncertainty

![Graph showing bunkering start, gas entrainments, and bunkering finish]
KROHNE OPTIMASS 6400:

- 0.1% error, most accurate single-phase flowmeter
- Direct mass flow measurement
- Independent density measurement
- Additional signals to provide diagnosis information
- Error curve is reproducible
Introduction

Coriolis flowmeter KROHNE OPTIMASS 6400:
• 0.1% error, most accurate single-phase flowmeter
• Direct mass flow measurement
• Independent density measurement
• Additional signals to provide diagnosis information
• Error curve is reproducible
Typical error curve under gas-liquid two-phase flow
Methodology

Existing analytical models

• Decoupling error

\[ E_{d,qm} = \frac{1-F}{1-\alpha} \alpha \]
Methodology

Existing analytical models

• Compressibility error  \[ E_{C,q_m} = \frac{1}{2} \left( \frac{\omega}{c} b \right)^2 \]
Methodology

Research Gap: factors not considered in existing models

- Decoupling error
  - GVF
  - Bubble size & distribution
- Compressibility error
  - Tube diameter
  - Vibration frequency
  - Speed of sound of fluid
- Damping
  - Liquid flowrate
  - Drive gain

![Graph showing relative error in mass flowrate against Reference GVF(%) with experimental data and model predicted results.](image-url)
Methodology

Improved analytical models

• Decoupling error

\[ E_{d,q_m} = \frac{1-F'}{1-\alpha} \alpha; \quad F' = C_F F (1 - \alpha) \]

• Compressibility error

• Adding damping error term

\[ E_E = C_E G_D \alpha q_m \]
Experimental Work

Layout of the test rig

- Water Tank
- Water centrifugal pump
- Air compressor
- Air reference thermal mass flowmeter
- Water reference Coriolis flowmeter
- Flow conditioner
- Sight glass
- Coriolis flowmeter under test
- DP transmitter
- Regulation valve
- Weighing system
- Flow conditioner
- DP transmitter
- Water
- Centrifugal pump
- Air injection locations
## Test matrix

<table>
<thead>
<tr>
<th>Data Sets</th>
<th>Injection Location</th>
<th>Flow conditioners</th>
<th>Temperature (°C)</th>
<th>Pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>data01</td>
<td>1 bottom</td>
<td>Hybrid@2U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data02</td>
<td>1 bottom</td>
<td>Hybrid@4U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data03</td>
<td>1 top</td>
<td>Grid@4D</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data04</td>
<td>1 top</td>
<td>Hybrid@2U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data05</td>
<td>1 top</td>
<td>Hybrid@4U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data06</td>
<td>2 bottom</td>
<td>Hybrid@2U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data07</td>
<td>2 bottom</td>
<td>Hybrid@4U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data08</td>
<td>2 top</td>
<td>Hybrid@2U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data09</td>
<td>2 top</td>
<td>Hybrid@4U</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data10</td>
<td>1 top</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data11</td>
<td>1 top</td>
<td>no</td>
<td>20</td>
<td>0.7</td>
</tr>
<tr>
<td>data12</td>
<td>1 top</td>
<td>no</td>
<td>40</td>
<td>0.2</td>
</tr>
<tr>
<td>data13</td>
<td>2 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data14</td>
<td>2 bottom</td>
<td>no</td>
<td>20</td>
<td>0.7</td>
</tr>
<tr>
<td>data15</td>
<td>2 bottom</td>
<td>no</td>
<td>40</td>
<td>0.2</td>
</tr>
<tr>
<td>data16</td>
<td>1 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data17</td>
<td>1 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data18</td>
<td>2 top</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data19</td>
<td>4 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data20</td>
<td>1 top</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data21</td>
<td>2 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data22</td>
<td>1 top</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data23</td>
<td>1 top</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data24</td>
<td>2 bottom</td>
<td>no</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data25</td>
<td>1 top</td>
<td>Swirl@2D</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data26</td>
<td>2 bottom</td>
<td>Swirl@2D</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data27</td>
<td>2 bottom</td>
<td>Grid@2D</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data28</td>
<td>1 top</td>
<td>Grid@2D</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>data29</td>
<td>1 top</td>
<td>Grid@4D</td>
<td>20</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Experimental Work

Typical test section (e.g. setup 1)

Water reference flowmeter

Meter under test
Experimental Work

Typical test section (e.g. setup 3 & 4)
Data Interpretation

- For the majority test setups:
  - Mass relative error is within 10%
  - GVF absolute error is within 5% (refer to paper for details)
  - Application range extended from 15% GVF to at least 40% GVF
For the minority test setups:

- Cannot predict as accurate especially at high flowrate
- Such test setups are not common in industry
Conclusions

• There are 2314 out of 2457 (94.2%) predictions of mass flowrate that are within 10% error
• There are 2403 out of 2457 (97.8%) predictions of GVF measurements are within 5% error
• The applicable range of the model is extended from maximum 15% GVF to at least 40% GVF
• A better understanding of the gas-liquid interaction inside the vibrating tubes of a Coriolis flowmeter is achieved.
The authors acknowledge Innovate UK for supporting the Knowledge Transfer Partnership (KTP) project