Experimental Analysis of the Fluid-Structure Interaction in a Model of Refrigeration Compressor Valve

Danilo Martins Arantes
Thiago Andreotti
José Luiz Gasche

UNESP-State University of São Paulo
Ilha solteira-SP
Brazil
Outline

Description of the problem
Why to study the problem
How we did it
What we obtained
What was the contribution
Description of the problem (1/5)

Compression mechanism of a reciprocating compressor

Gas is sucked

Gas is pumped
Description of the problem (2/5)

Valve example

Suction Valve

Discharge Valve
Valve works as a cantilever
The dynamics of the valve depends on the forces produced by the gas flow.
And the dynamics of the flow depends on the forces produced by the reed
This is a fluid-structure interaction problem
Why should we study the problem? (1/4)

Reduction of the energy consumption

Thermodynamic Losses

- Discharge process: 49%
- Suction process: 22%
- Gas superheating: 25%
- Gas leakage: 4%

Ribas et al. (2010)
Why should we study the problem? (2/4)

Importance of the thermodynamic efficiency

Ribas et al. (2010)

Thermodynamic: 83%
Mechanical: 88%
Electrical: 92%
Why should we study the problem? (3/4)

Domestic electrical energy consumption in Brazil

- Domestic refrigeration: 53%
- Air Conditioning: 22%
- Freezers: 20%
- Others: 5%

Eletrobras, 2005
Suction and discharge processes contribute with 47% for the thermodynamics losses

Energy save

- Thermodynamic Efficiency of 83%
- 47% of the domestic energy consumption
How did we study the problem?

Valve design

Numerical approach
- Flexibility
- Lower cost

Experimental approach
- Need
- Code validation
- Data for code validation
- Difficult to find
Objective

Produce experimental data for validating numerical codes developed to solve fluid-structure interaction in compressor valves
Experimental apparatus-general view

- flexible tube
- fine net
- aluminum tube
- test section
- spacer bar
- concrete base
- mass flow rate control valve
- pressure control valve
- mass flow meter
- filter
- air reservoir
- air reservoir
Experimental apparatus-general view
Experimental apparatus—test section

[Diagram of experimental apparatus with labeled parts: feeding orifice, aluminum tube, upper plate, bottom plate, reed, spacer bar, optical sensor, displacement measurement position, dimensions 22.0 mm, 55.5, 82.5, d=34.9]
Experimental operation conditions

<table>
<thead>
<tr>
<th>Working Fluid</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank pressure</td>
<td>11 to 12 bar</td>
</tr>
<tr>
<td>Temperature</td>
<td>25°C</td>
</tr>
<tr>
<td>Reynolds number</td>
<td>2,000 to 12,000</td>
</tr>
</tbody>
</table>
Typical experimental test (1/2)

Upper plate

reed

Optical sensor
Typical experimental test (2/2)
Experimental Results (1/16)

Instantaneous displacement of the reed for Re=10,000

Data Repeatability

Amplitude (mm)

Test 1
Test 2
Test 3

Amplitude (mm)

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

0.050 0.055 0.060 0.065 0.070 0.075 0.080 0.085 0.090 0.095 0.100

t (s)
Instantaneous displacement of the reed for Re=2,000
Instantaneous displacement of the reed for Re=5,000
Experimental Results (3/16)

Instantaneous displacement of the reed for Re=5,000

Graphs showing the amplitude of displacement over time for two different Reynolds numbers (Re=2,000 and Re=5,000)
Experimental Results (4/16)

Instantaneous displacement of the reed for Re=10,000
Instantaneous displacement of the reed for Re=10,000

---

Experimental Results (5/16)

---
Instantaneous displacement of the reed for Re=12,000
Instantaneous displacement of the reed for Re=12,000
Experimental Results (8/16)

Instantaneous displacement of the reed for Re=10,000

![Graph showing instantaneous displacement with marked areas for deceleration and fast acceleration.]
Experimental Results (9/16)

Instantaneous displacement of the reed for Re=10,000
Experimental Results (10/16)

Instantaneous displacement of the reed for Re=10,000

With impact

Without impact
Experimental Results (11/16)

Self-induced vibration

Force variation with reed angle

Detachment of vortex

Possible explanation

α = 6.25°
Dominant frequency for Re=10,000

- 115.9 Hz
### Dominant frequencies

<table>
<thead>
<tr>
<th>Reynolds</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000</td>
<td>126.0</td>
<td>124.6</td>
<td>124.6</td>
<td>125.0±0.4</td>
</tr>
<tr>
<td>3,000</td>
<td>121.7</td>
<td>120.2</td>
<td>120.2</td>
<td>120.7±0.4</td>
</tr>
<tr>
<td>4,000</td>
<td>120.2</td>
<td>120.2</td>
<td>120.2</td>
<td>120.2±0.0</td>
</tr>
<tr>
<td>5,000</td>
<td>118.8</td>
<td>118.8</td>
<td>118.8</td>
<td>118.8±0.0</td>
</tr>
<tr>
<td>6,000</td>
<td>118.8</td>
<td>117.3</td>
<td>117.3</td>
<td>117.8±0.4</td>
</tr>
<tr>
<td>7,000</td>
<td>117.3</td>
<td>117.3</td>
<td>117.3</td>
<td>117.3±0.0</td>
</tr>
<tr>
<td>8,000</td>
<td>117.3</td>
<td>115.9</td>
<td>115.9</td>
<td>116.4±0.4</td>
</tr>
<tr>
<td>9,000</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9±0.0</td>
</tr>
<tr>
<td>10,000</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9±0.0</td>
</tr>
<tr>
<td>12,000</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9</td>
<td>115.9±0.0</td>
</tr>
</tbody>
</table>
Experimental Results (14/16)

Dominant frequencies

![Graph showing dominant frequencies with data points for Test 1, Test 2, and Test 3.]
### Maximum displacement of the reed

<table>
<thead>
<tr>
<th>Reynolds s</th>
<th>$s_{\text{max}}$ (mm) Test 1</th>
<th>$s_{\text{max}}$ (mm) Test 2</th>
<th>$s_{\text{max}}$ (mm) Test 3</th>
<th>$s_{\text{max}}$ (mm) Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000</td>
<td>0.703</td>
<td>0.737</td>
<td>0.719</td>
<td>0.72±0.01</td>
</tr>
<tr>
<td>3,000</td>
<td>1.015</td>
<td>1.073</td>
<td>1.073</td>
<td>1.05±0.02</td>
</tr>
<tr>
<td>4,000</td>
<td>1.320</td>
<td>1.361</td>
<td>1.361</td>
<td>1.35±0.01</td>
</tr>
<tr>
<td>5,000</td>
<td>1.596</td>
<td>1.666</td>
<td>1.657</td>
<td>1.64±0.02</td>
</tr>
<tr>
<td>6,000</td>
<td>1.936</td>
<td>1.985</td>
<td>1.960</td>
<td>1.96±0.01</td>
</tr>
<tr>
<td>7,000</td>
<td>2.239</td>
<td>2.287</td>
<td>2.297</td>
<td>2.27±0.02</td>
</tr>
<tr>
<td>8,000</td>
<td>2.542</td>
<td>2.615</td>
<td>2.573</td>
<td>2.58±0.02</td>
</tr>
<tr>
<td>9,000</td>
<td>2.814</td>
<td>2.862</td>
<td>2.841</td>
<td>2.84±0.01</td>
</tr>
<tr>
<td>10,000</td>
<td>3.036</td>
<td>3.099</td>
<td>3.069</td>
<td>3.07±0.02</td>
</tr>
<tr>
<td>12,000</td>
<td>3.475</td>
<td>3.535</td>
<td>3.490</td>
<td>3.50±0.02</td>
</tr>
</tbody>
</table>
Experimental Results (16/16)

Maximum displacement of the reed

![Graph showing maximum displacement of the reed with data points for Test 1, Test 2, and Test 3.]
Contribution

Reliable experimental data that can be used to validate numerical code developed to solve the fluid-structure interaction problem in refrigeration compressor valves.
Acknowledgments
Thank you for your attention