Miniature Piezoelectric Compressor for Joule-Thomson Cryocoolers

Sergey Sobol\textsuperscript{a}, Nir Tzabar\textsuperscript{b}, Gershon Grossman\textsuperscript{a}

\textsuperscript{a}Technion – Israel Institute of Technology, Haifa, Israel 32000

\textsuperscript{b}Rafael, Haifa, Israel 3102102
Outline

- Motivation
- Design Concept
- Analysis
- Experimental Results
- Summary
Motivation

- Developing a compressor for Joule-Thomson Cryocoolers:
  - Low pressure = 0.1 MPa
  - High pressure = 2.5 MPa
  - Flow Rate = 5 slpm (~0.1 g/s)

- Long life
- Low vibrations
**Design Concept**

**Second Stage**
- Small displacement
- High pressure difference
- No amplification

**First Stage**
- Large displacement
- Low pressure difference
- Displacement amplification
Design Concept

- **First Stage**
  - High Pressure
  - Inter-cooling
  - Valve Units
  - Compression Volumes
  - Pistons
  - Piezoelectric Actuators

- **Second Stage**
  - Low Pressure
  - Displacement Amplifier Unit
Design Concept

Compression volume

High Pressure

Intermediate Pressure

Valve Unit

Hydraulic fluid

Compression Volume

Elastomeric Membrane

Metallic Membrane

Piston

Piezoelectric Actuator
Design Concept

Compression volume + Displacement amplifier

- Intermediate Pressure
- Compression Volume
- Elastomeric Membrane
- Metallic Membranes
- 1st Piston
- 2nd Piston
- Hydraulic Liquid
- Valve Unit
- Low Pressure
- Piezoelectric Actuator
Design Concept

Structure stiffness

Structural deformations:
1. Housing cover deflection
2. Axial elongation of the housing
3. Deflection of the piston
4. Deflection of the membrane

Additional sources of elasticity:
5. Compressibility of the liquid
6. Mechanical contacts
7. Threads
Analysis

The quasistatic relation between the supply voltage to the piezoelectric element and the piston displacement

\[ N \cdot V_{\text{PZT}} = \frac{k_{\text{PZT}}}{a} x + a \left( 1 + \frac{k_{\text{PZT}}}{k_{\text{str}}} \right) \left[ \Delta p(x) A + k_{\text{prl}} x \right] \]

The relation between the piezoelectric displacement and the piston displacement

\[ x_{\text{PZT}} = \frac{x}{a} + \frac{\Delta p(x) A + k_{\text{prl}} x}{k_{\text{str}}} \]
**Analysis**

**Check valves**

Outlet valve:
\[
M_1 \ddot{x}_1 + f_1 \dot{x}_1 + k_1 x_1 = P A_{1,2} - P_{out} A_{1,1} + \frac{P + P_{out}}{2} (A_{1,1} - A_{1,2}) - k_1 x_{1,0} + \frac{\dot{m}_{out}^2}{\rho A_{1,2}}
\]

Inlet valve:
\[
M_2 \ddot{x}_2 + f_2 \dot{x}_2 + k_2 x_2 = P_{in} A_{2,2} - P A_{2,1} + \frac{P_{in} + P}{2} (A_{2,1} - A_{2,2}) - k_2 x_{2,0} + \frac{\dot{m}_{in}^2}{\rho_{in} A_{2,2}}
\]
Experimental Results

Experimental setups
Experimental Results

Experimental setups
## Experimental Results

<table>
<thead>
<tr>
<th>Compression Stage</th>
<th>Frequency [Hz]</th>
<th>Low Pressure [MPa]</th>
<th>Intermediate Pressure [MPa]</th>
<th>High Pressure [MPa]</th>
<th>Flow Rate [mg/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>50</td>
<td>-</td>
<td>0.5</td>
<td>2.4</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>-</td>
<td>0.5</td>
<td>2.1</td>
<td>13.4</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>-</td>
<td>0.5</td>
<td>2.2</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>0.155</td>
<td>0.506</td>
<td>-</td>
<td>13.4</td>
</tr>
<tr>
<td>1</td>
<td>200</td>
<td>0.149</td>
<td>0.503</td>
<td>-</td>
<td>21.4</td>
</tr>
<tr>
<td>1+2</td>
<td>100</td>
<td>0.15</td>
<td>-</td>
<td>2.1</td>
<td>13.4</td>
</tr>
<tr>
<td>1+2</td>
<td>200</td>
<td>0.15</td>
<td>-</td>
<td>2.2</td>
<td>21</td>
</tr>
</tbody>
</table>

### Requirements:

- Low Pressure: 0.1
- Intermediate Pressure: 2.5
- High Pressure: 100
**Summary**

The compressor is designed to provide a relatively high compression ratio in comparison with other piezoelectric driven compressors described in the literature.

The design concept has been presented.

Preliminary results show a pressure ratio of 1:14.7 with a flow rate of 0.021 g/s.

Further development shall improve these results by increasing the pressure ratio and/or the flow rate.
Questions?

Prof. Gershon Grossman - grossmng@tx.technion.ac.il

Dr. Nir Tzabar - nirtzabar8@gmail.com