MEMS Technology - MicroElectroMechanical Systems

MEMS based Coriolis
Current Coriolis what do they Measure?

- Phase shift
- Resonance Frequency
- Temperature

What can we do with these measurements?
- Phase shift -> massflow
- Resonance Frequency -> Density
- Temperature -> for compensation

How about volume flow?
- Calculated from Density and Massflow measurements
The measuring principle

https://youtu.be/gxYniN5WQjI
Accuracy!

- How accurate can we measure mass flow with a Coriolis flowmeter?
  0.05% of measured value of a liquid
- How accurate can we measure Volume flow?
  This depends highly on the accuracy of the density accuracy!
  Ideally it has the same accuracy as mass flow -> in Praxis it hasn’t!
- Why?
  Because density measurement is dependent on temperature (compensated), mechanical restrictions and calibration!
- What is a good accuracy for a Coriolis based density meter?
  About 1 kg/m³ (Within a certain density and temperature range)
- For liquid (i.e. water) this is 0.1% so a good accuracy
  This could result in Volume flow accuracy of 0.1% in Liquid
How about gas?

- Just one example
  Air at atmospheric conditions
- What is the density?
- About 1.2 kg/m³
- What was the absolute accuracy of the density measurement?
- 1 kg/m³ -> error about 80%
- That’s why you can’t measure actual volume flow with a Coriolis meter of a gas (you can calculate norm Volume flow)
What is MEMS?

MEMS – MicroElectroMechanicleSystem

- “MEMS claim to be the smallest functional machines that are currently engineered by humans. MEMS is an exciting field with rapidly growing commercial importance.”


- Wafer → Cleanroom processes → MEMS-Chip
“A central dilemma and at the same time one of the best features of MEMS is its incredibly wide range of applications.”

A MEMS based Coriolis Massflowmeter?

- Thin-film Temperature Sensor
- Microchanel
- Sensing electrodes
- Driving Electrode
MEMS-Coriolis-Sensor

Promass X
14” Coriolis Flow Meter
(1230mm x 1714mm x 695mm)
The E+H MEMS-Coriolis-Sensor

- Freestanding micro channel
- Fabricated by silicon micro machining
- Channel volume: 500nl
- Channel cross-section: 160 µm x 200 µm
- Burst pressure: 80bar
- Resonant frequency: > 25 kHz

- Surface roughness micro channel
- < 1 µm

- Excitation and sensing method
- Capacitive
Nanomass Gas Density measuring principle

- The flow tube is oscillating in its first eigenmode
- The resonant frequency of the tube depends on the fluid density

\[ f \propto \frac{E \cdot I}{\sqrt{\rho_{Tube} \cdot A_{Tube} + \rho_{Fluid} \cdot A_{Fluid}}} \]

- \( f \) : Eigenfrequency (Eigenmode)
- \( E \cdot I \) : Tube stiffness
- \( \rho_{Tube} \) : Tube material density
- \( A_{Tube} \) : Tube diameter
- \( \rho_{Fluid} \) : Fluid density
- \( A_{Fluid} \) : Fluid diameter
Gas density – silicon is the enabler!

\[ \frac{\rho_{\text{steel}}}{\rho_{\text{silicon}}} = \frac{m_{\text{steel}}}{m_{\text{silicon}}} = 3.4 \]

Steel tube

Silicon Chip

The advantage of a silicon micro channel:
- Better tube-to-fluid weight ratio
- Results in a higher resonance frequency
- Offers an increased sensitivity
- Resonating in vacuum = decoupled from sources of noise = allows measurement at atmospheric pressure

Liquids only

Liquids & Gas
Chip fabrication

- Wide range of micro-fabrication:
  - (4 wafer-stack & appr. 65 single process steps)
    - Photolithography
    - Reactive-ion etching
    - Cryo-etching (-176°C)
    - Wet etching
    - Thermal oxidation (950°C)
    - Structured metallization
    - Si-fusion bonding (1050°C, 8h)
    - Anodic Si-Glass bonding (350°C, 8h)
    - Chip dicing
Nanomass Gas Density technical specification

Fluid
- non-corrosive gases, combustible and non-combustible (no Helium)
- Dry and dust free

Installation conditions
- Inline or bypass
- Ex or safe area

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Density range gas</td>
<td>0 – 30 kg/m³</td>
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<tr>
<td>Flow range:</td>
<td>&lt;1 liter/min</td>
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<tr>
<td>Accuracy</td>
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<tr>
<td>Repeatability</td>
<td>0.05 kg/m³</td>
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<td>Resolution</td>
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<td>Process temperature range</td>
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<tr>
<td>Accuracy</td>
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<tr>
<td>Resolution:</td>
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<tr>
<td>Permitted system pressure</td>
<td>20 bar a</td>
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Thank you very much for your attention