5.1 Speed, Forces and Torque

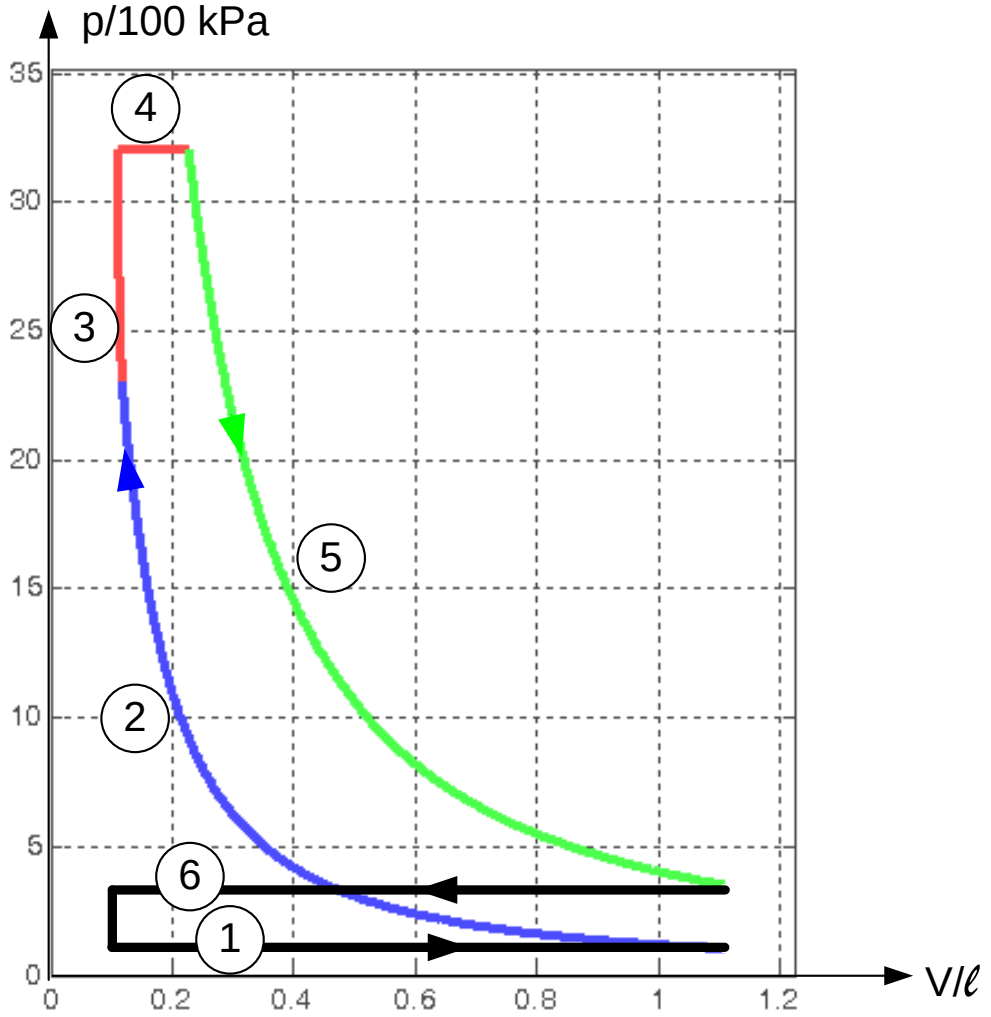
5.2 Exhaust Gas Analysis

5.3 Temperatures, Pressures and Flows

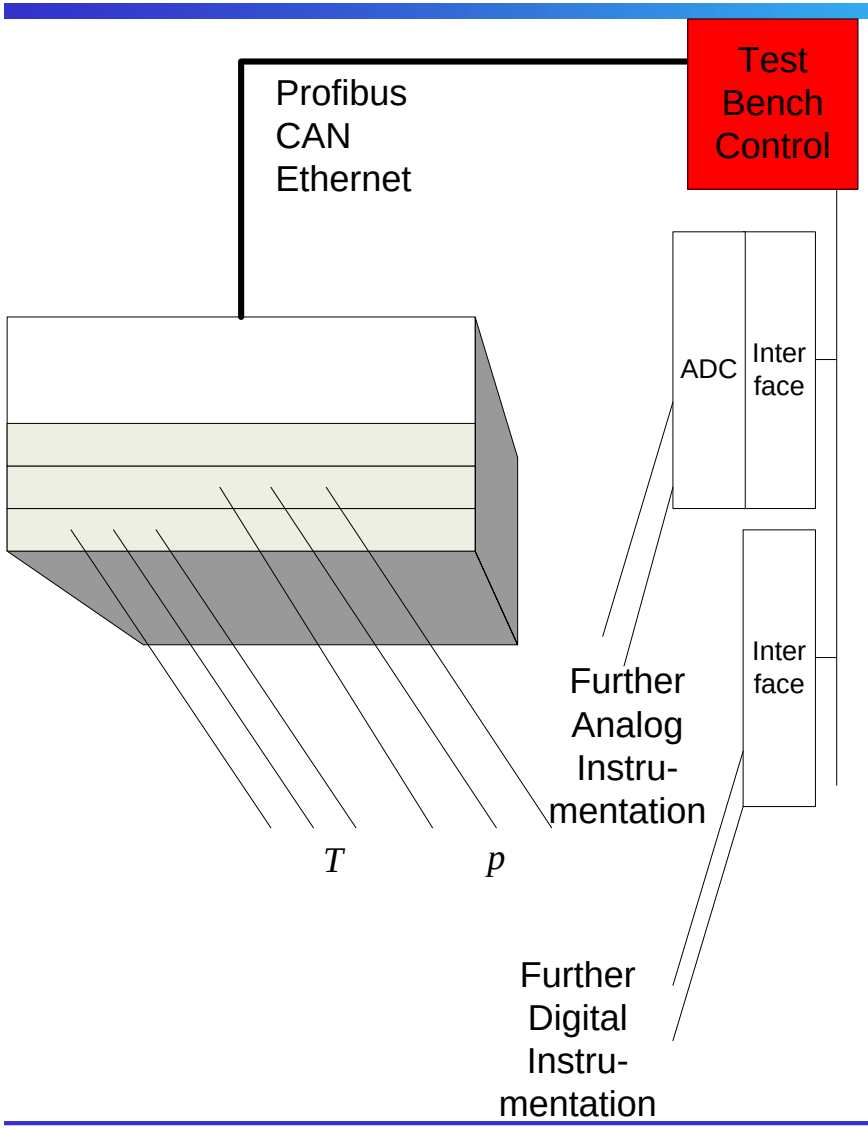
5.4 Combustion Analysis

Seiliger Process

1: Intake
2: Compression
3: Ignition
4: Isobaric Heating
5: Expansion
6: Exhaust



Temperatures, Pressures and Flows
Practical Arrangement of Instrumentation



ADC: Analog Digital Converter

5.3.1 Temperature Measurement

5.3.2 Pressure Measurement

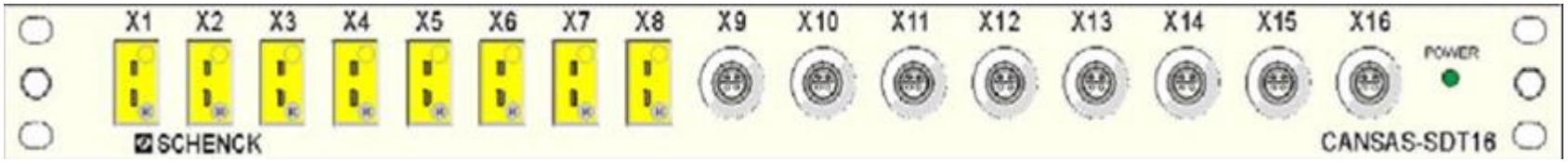
5.3.3 Flow Measurement

Temperatures (Examples)

• **Inlet Manifold**	**-20 °C ... 60 °C**
• **Boost Air**	**-20 °C ... 250 °C**
• **Exhaust Gas**	**0 °C ... 1000 °C**
• Cylinder	> 1000 °C
• Fuel	-20 °C ... 100 °C
• Coolant	-20 °C ... 150 °C
• Oil	-20 °C ... 150 °C

Temperature Sensors

- **PTC (Positive Temperature Coefficient, R increases with T)**
  - **Ceramic PTC**
  - **Silicon PTC**
  - **Metal PTC**
- **NTC (Negative Temperature Coefficient, R decreases with T)**
- **Thermocouples (U increases with T)**
- **Touchless Sensors**



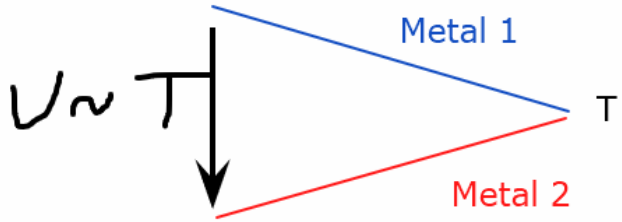
Source: Horiba

Metal PTC

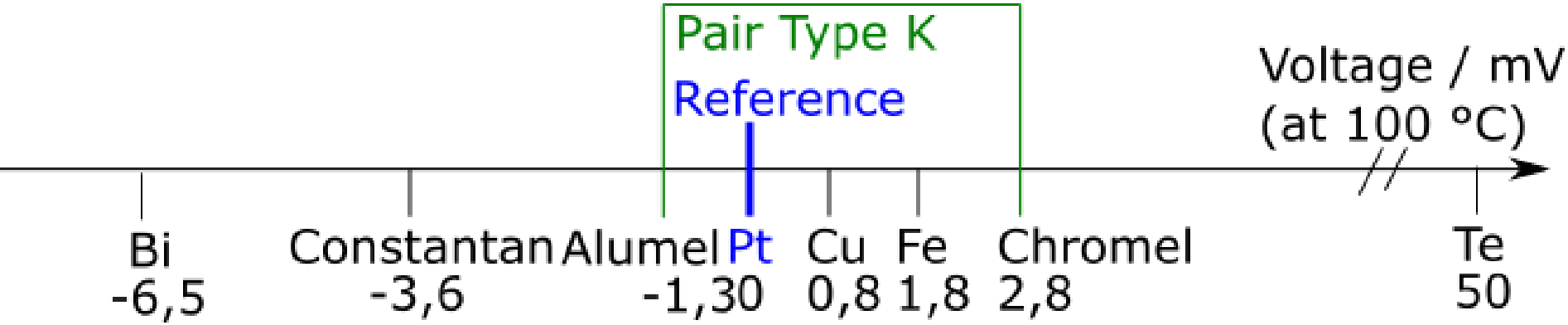
Platinum PTC
(e.g. PT100 with 100 Ω @ 0 °C)

Source: Heraeus Sensor Technology GmbH, Kleinostheim (Yageo)

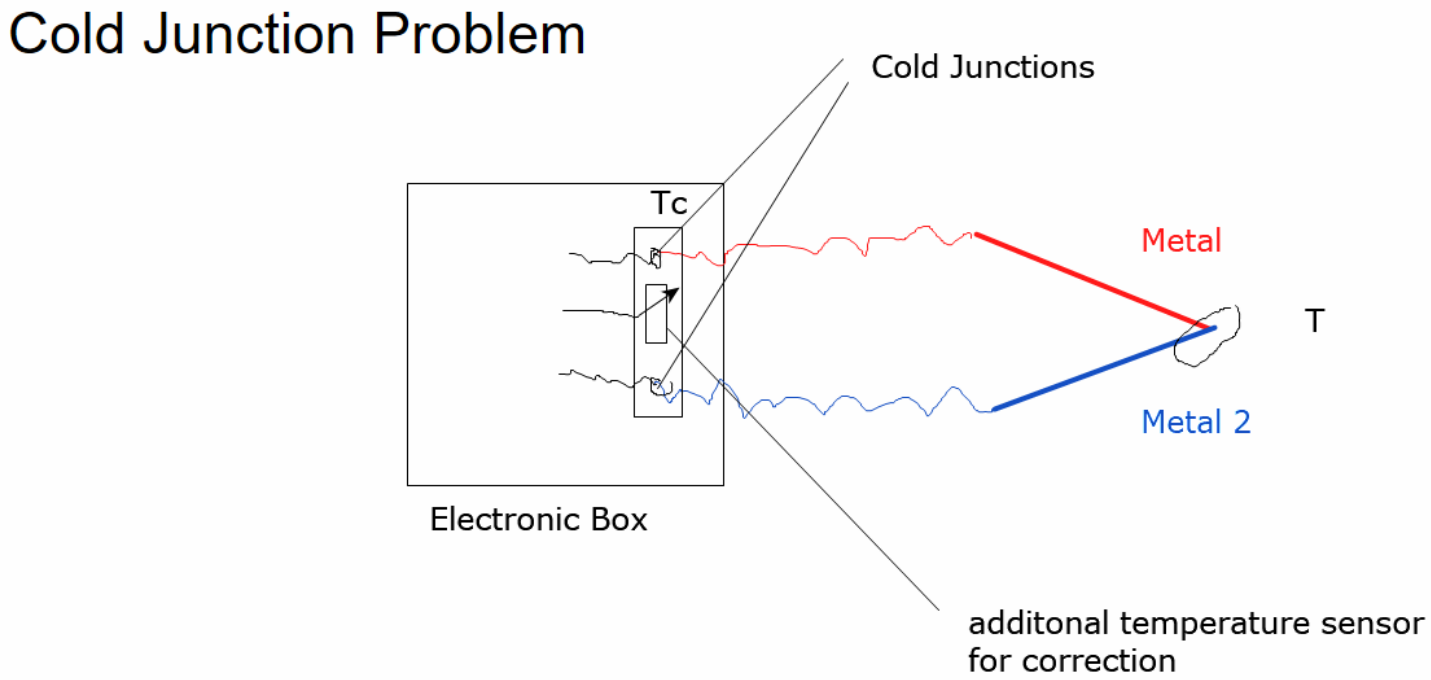
Thermocouples



Thermoelectric series



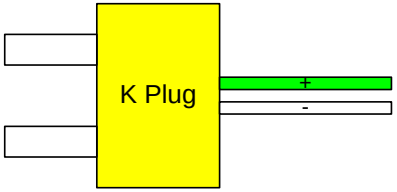
Thermocouples

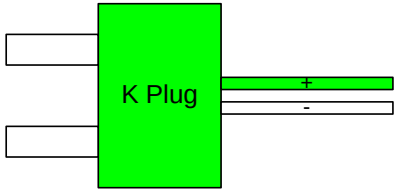


Thermocouples

K: ... 1250 °C

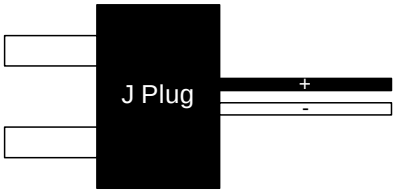
Standard Type



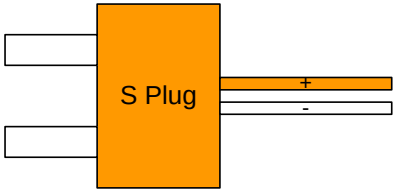


J: ... 750 °C

Higher Sensitivity than K



S: **... 1600 °C**



Touchless Sensors

Source: http://www.dias-infrared.de

5.3.1 Temperature Measurement

5.3.2 Pressure Measurement

5.3.3 Flow Measurement

Relative Pressures
(often smaller range, higher accuracy)

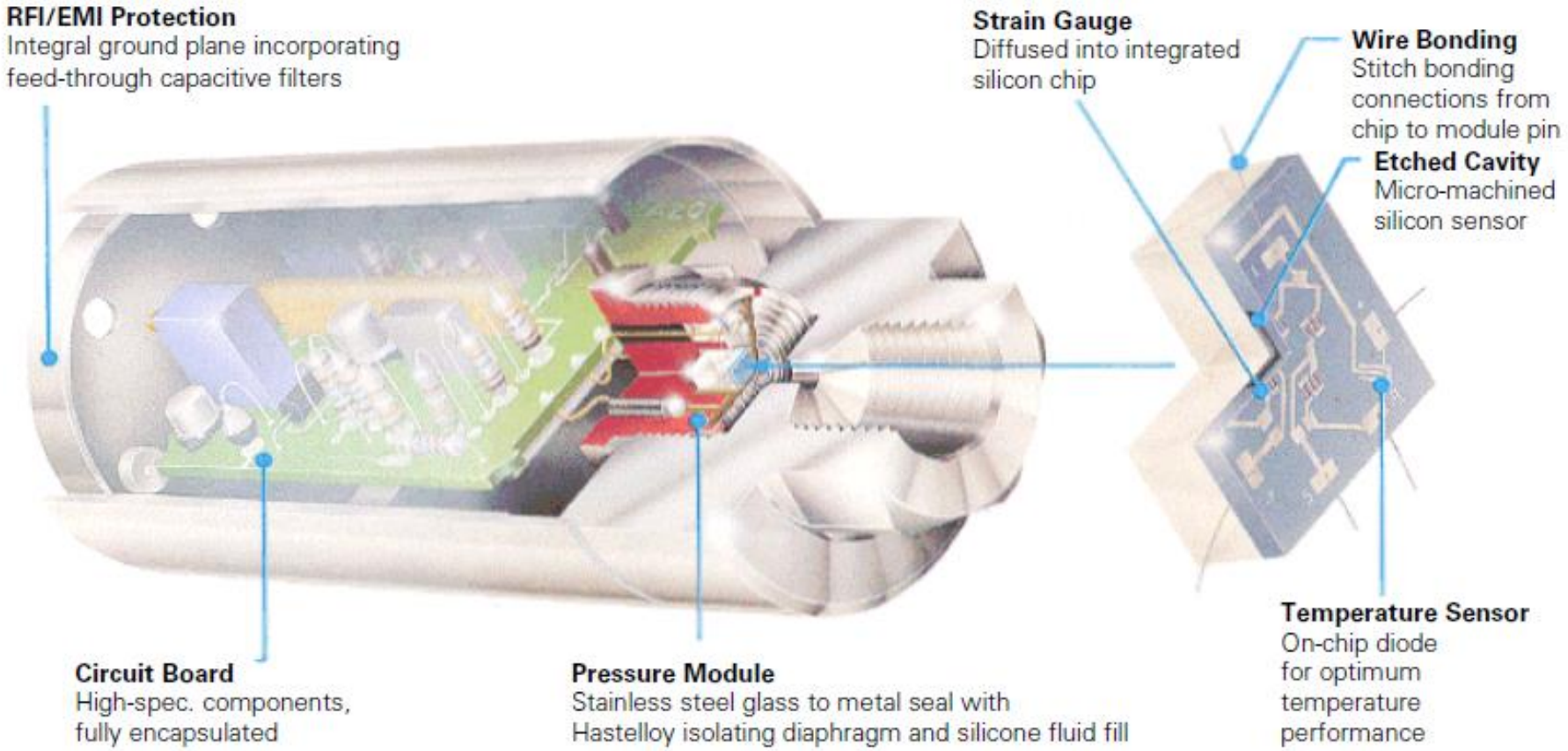
• **Manifold Air Pressure (MAP)**	**-1 bar ... 1 bar, ≤ 4 bar**
• **Boost Pressure**	**-1 bar ... 4 bar, ≤ 8 bar**
• Exhaust Backpressure	0 bar ... 1 bar, ≤ 3 bar
• Cylinder (Indicator)	> 100 bar
• Fuel (Low Pressure)	0 bar ... 6 bar, ≤ 15 bar
• Fuel (Common Rail)	> 3000 bar
• Oil	0 bar ... 16 bar, ≤ 32 bar

Pressures

Pressure Module with Integrated Transducers

Source: AVL

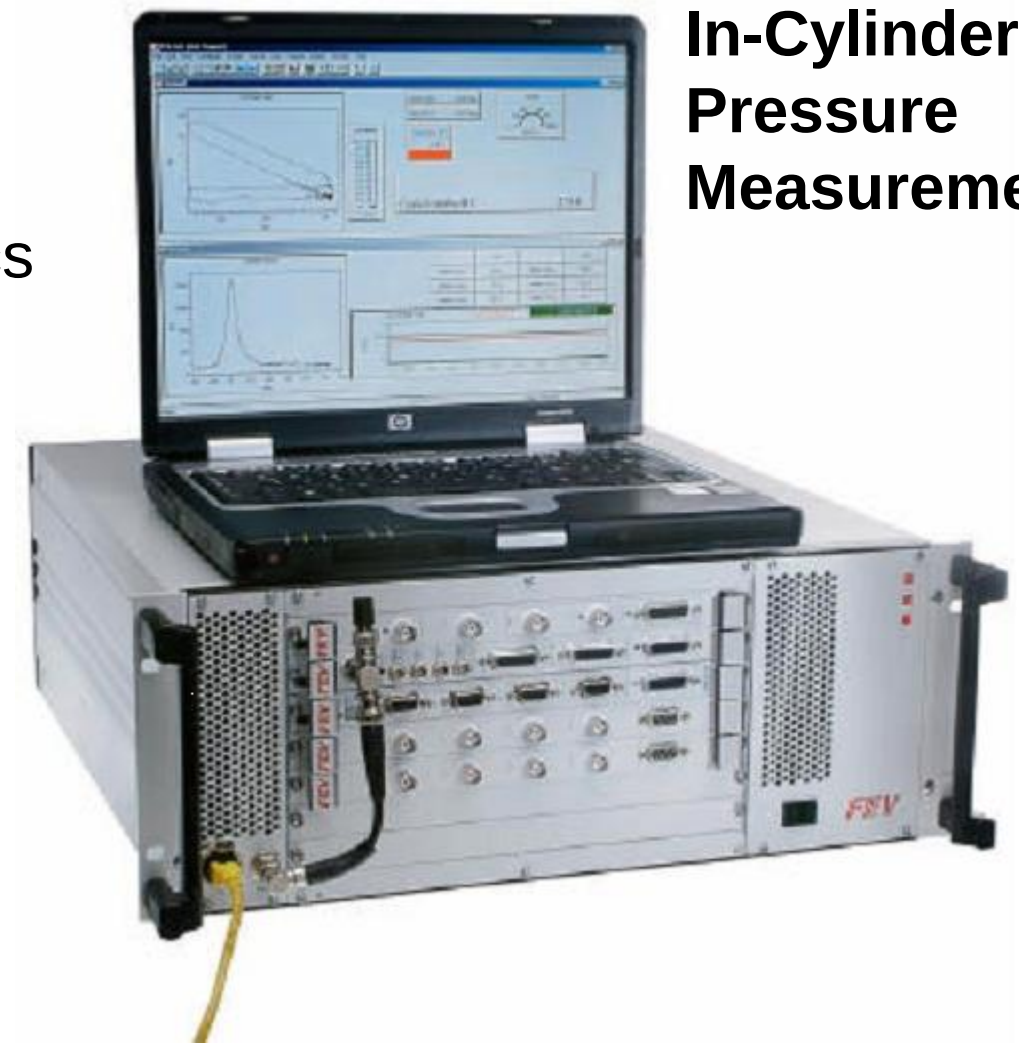
Pressures



Source: Druck ltd.

Applications:

Max Pressure
Thermodynamics
Ignition Analysis



In-Cylinder Pressure Measurement

Source: FEV

5.3.1 Temperature Measurement

5.3.2 Pressure Measurement

5.3.3 Flow Measurement

Flows

- **Inlet Air**
- Boost Air
- EGR
- Exhaust Gas
- Blowby Gas
- **Fuel**
- Coolant
- Oil

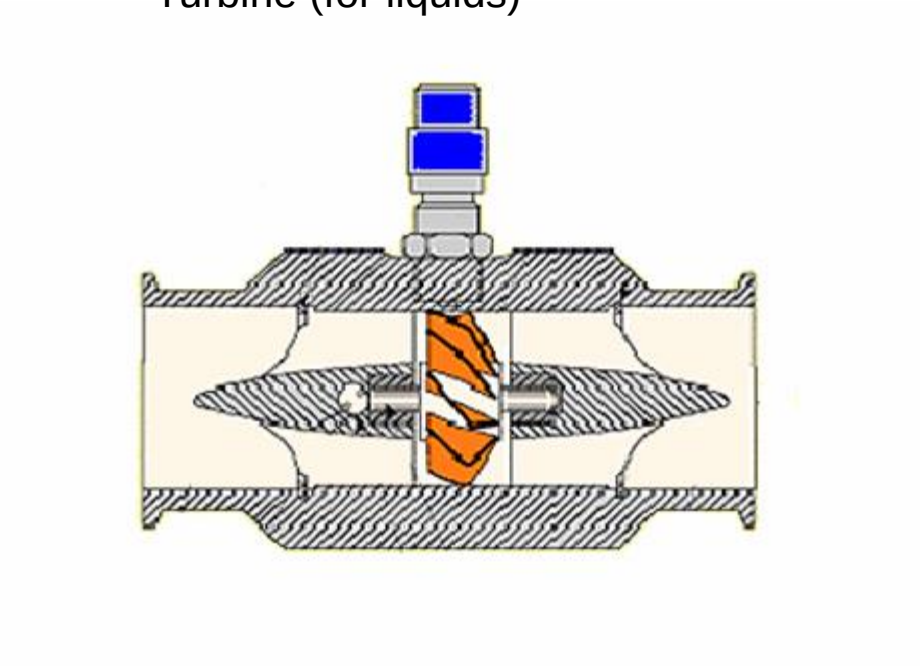
A Few Measurement Principles

- Turbine ($\mathrm{d}V/\mathrm{d}t$)
- Pressure Differences ($\mathrm{d}V/\mathrm{d}t$)
- Thermal ($\mathrm{d}m/\mathrm{d}t$)
- Coriolis ($\mathrm{d}m/\mathrm{d}t$)
- Runtime ($\mathrm{d}V/\mathrm{d}t$)
- Aerosols: Electrostatic
- Fuel Consumption: Tank Monitoring

Source: Wikimedia Commons, User “Alfaomega”

Flows

Turbine (for liquids)



Source: Wikimedia Commons, User “Alfaomega”

Flows

Pressure Difference: Venturi

Continuity Equation:

Bernoulli Equation: $p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$

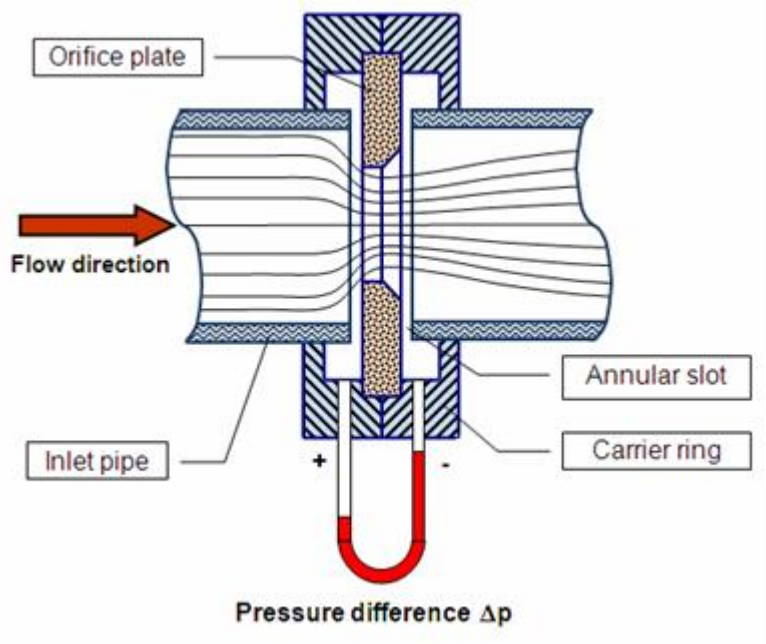
→ Pressure Difference

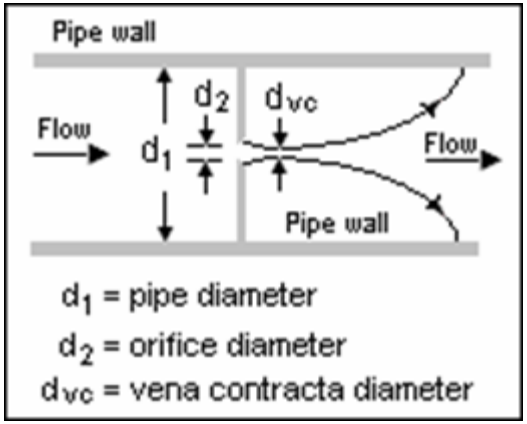
A: Cross Sections

$$\Delta p = \frac{1}{2}\rho \dot{V}^2 \left(\frac{1}{A_2^2} - \frac{1}{A_1^2} \right)$$

Flows

Pressure Difference: Orifice Plate





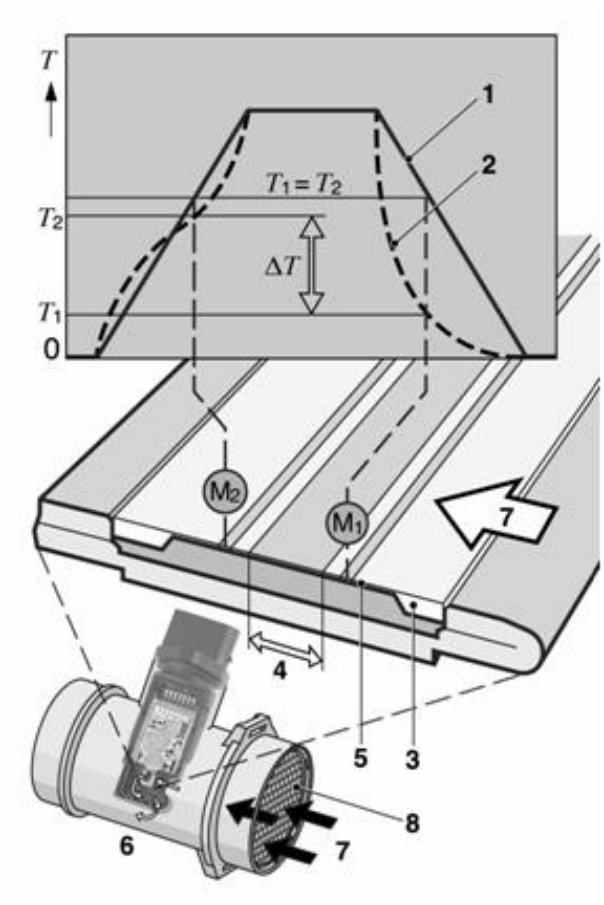
Source: Wikipedia

Flows

Blow By Meter with Orifice tubes

Source: AVL

Flows



Hot Film Meter

(HFM)

4 Heating Area
M1, M2 Measurement Zone

Source:
Robert Bosch GmbH

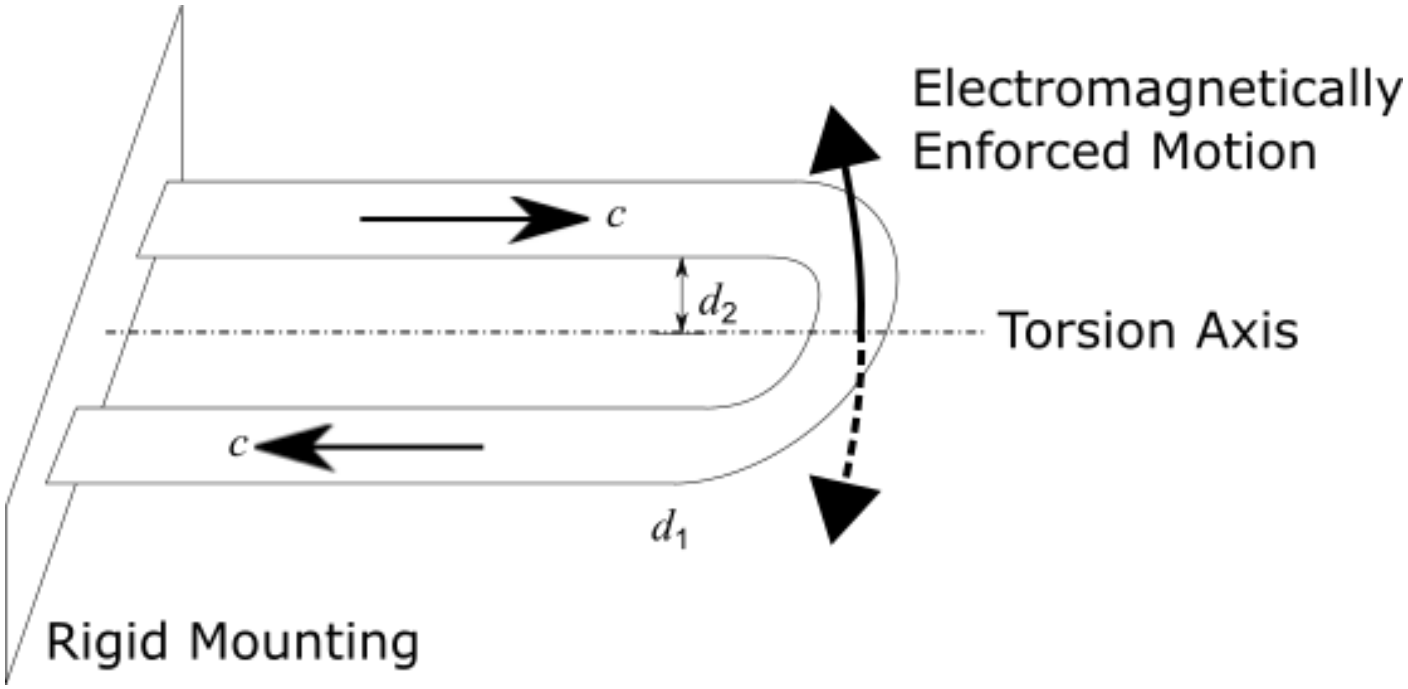
Flows

Hot Wire Anemometer ABB “Sensyflow”

Source: Horiba

Flows

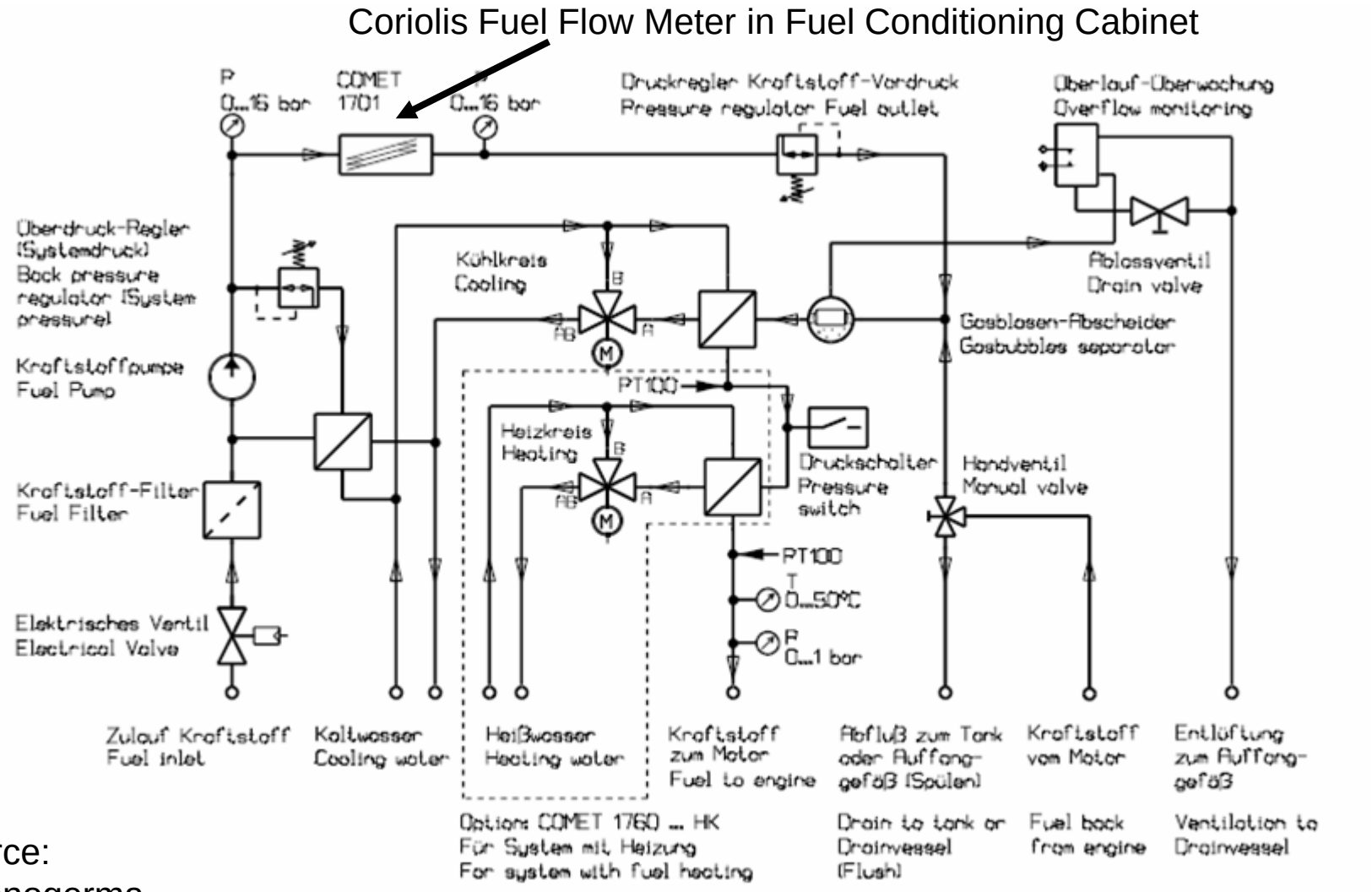
Principle of Coriolis
Flow Sensor



Flows

Coriolis Fuel Flow Meter in Fuel Conditioning Cabinet

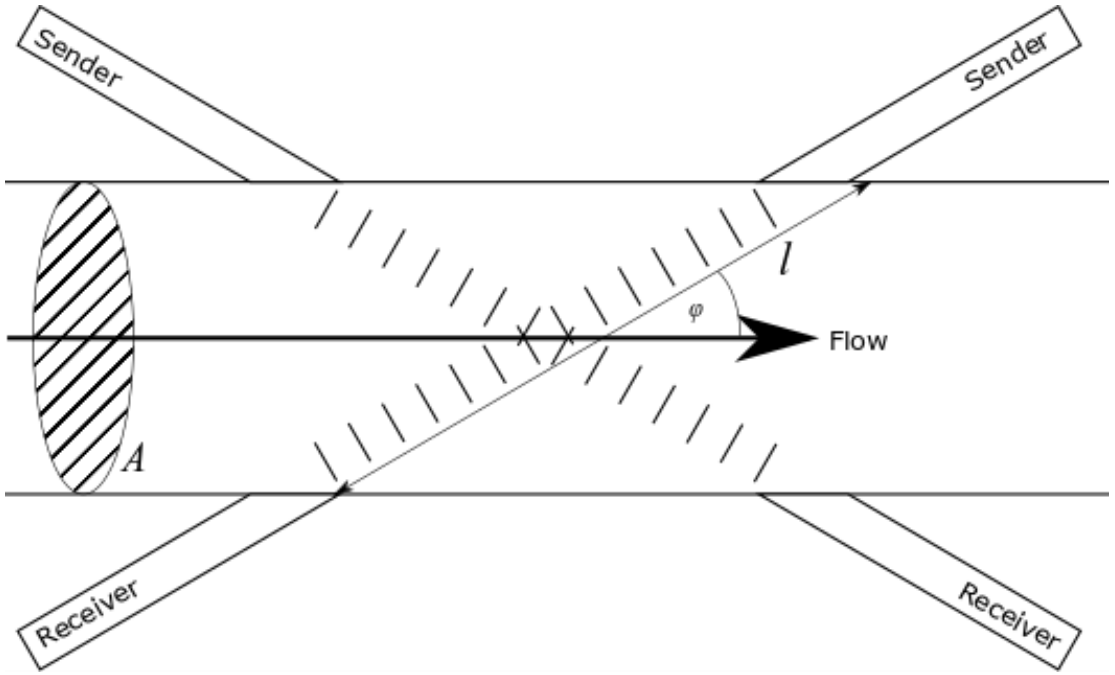
Flows



Source:
Technogerma

Flows

Runtime (e. g. FEV air flow meter)



$$\frac{dV}{dt} = \frac{Al}{2\cos(\varphi)}\left(\frac{1}{t_f} - \frac{1}{t_r}\right)$$