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Effects of inclination of a clearance-sealed piston prover on the leakage flow rate

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Piston prover

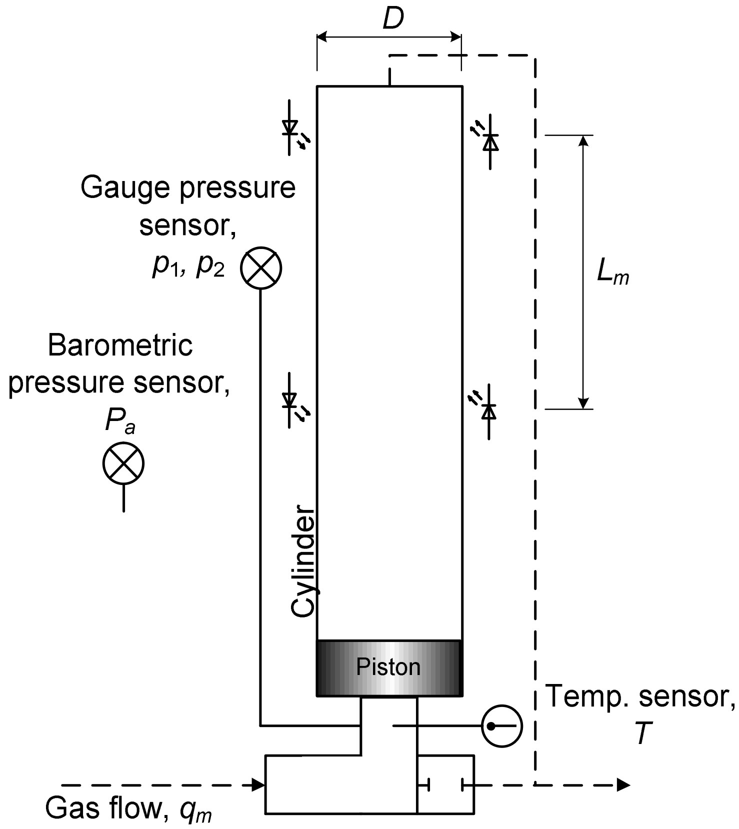
- How does it work?

- Basic equation

$$q_v = \frac{V_m}{\Delta t} = \frac{\pi D^2 L_m}{4 \Delta t}$$

+

additional corrections



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Piston prover

- Measurement model for gas flow rate

$$q_m = \rho(p_a, T) q_v(p_a, T)$$

$$q_v(p_a, T) = \left(\frac{V_m}{\Delta t} + q_{v,l} \right) \varepsilon_\rho$$

→ density correction factor

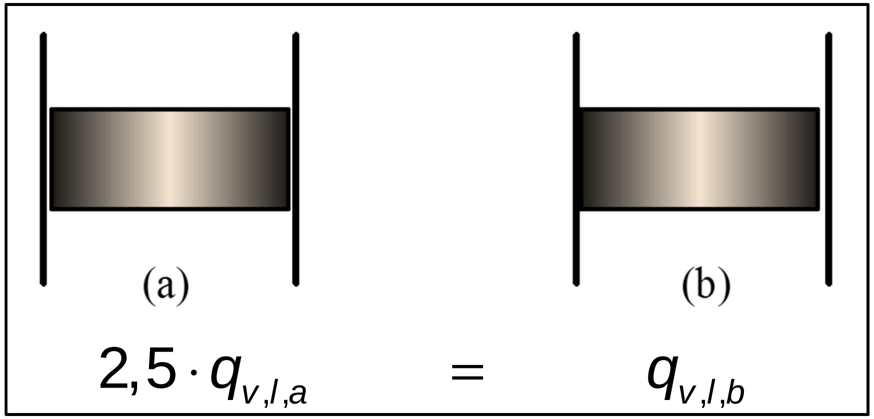
leakage flow rate

! highest uncertainty contribution at smallest flow rates

Leakage flow rate

- Poiseuille flow

$$q_{v,l} = \frac{\pi D \delta^3}{12\mu}\frac{\Delta p}{H}$$



- we do **not** know how piston actually travels → it has to be measured

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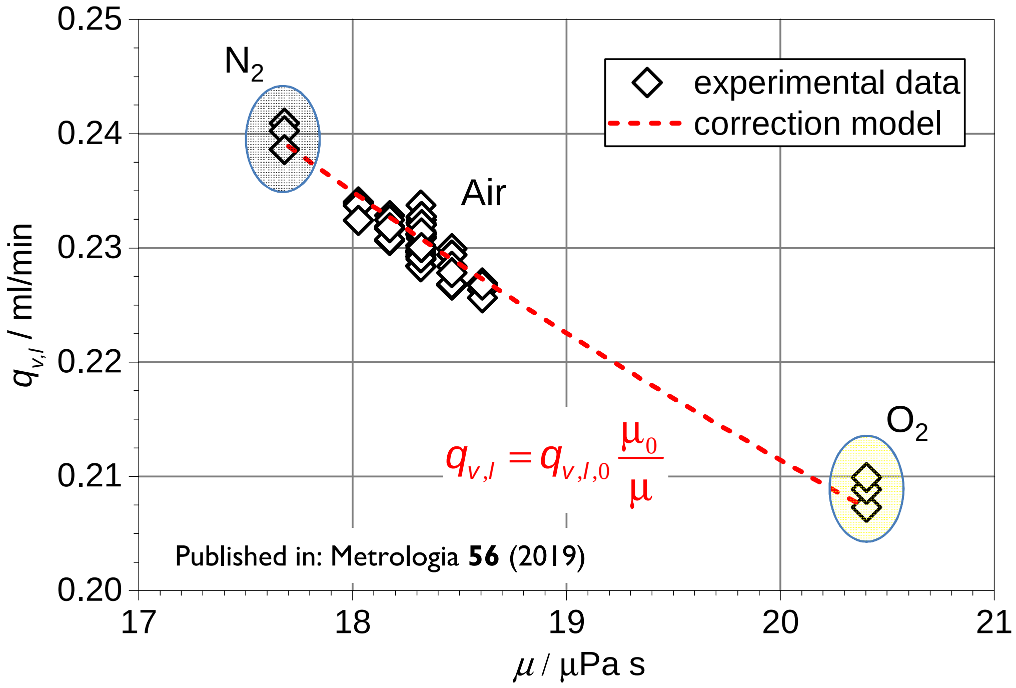
Leakage flow rate

- correction model (type of fluid, temperature)



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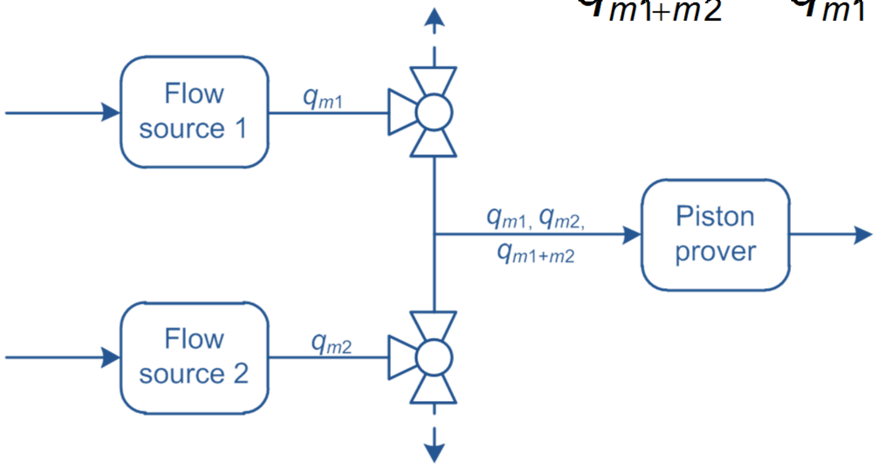
Dynamic summation method

$$q_{m1+m2} = q_{m1} + q_{m2} \quad \text{and} \quad q_m = q_m^* + q_{m,l}$$



$$q_{m,l} = q_{m1+m2}^* - q_{m1}^* - q_{m2}^*$$

$$q_{v,l} = \frac{q_{m,l}}{\rho \varepsilon_\rho}$$

- test result:

$$q_{v,l} = \frac{1}{N}\sum_{i=1}^{N} q_{v,l,i}, \quad s\left(q_{v,l}\right) = \sqrt{\frac{s^2\left(q_{v,l,i}\right)}{N}\left(1 + \frac{2\left(N-1\right)\hat{R}}{N}\right)}, \quad N = 10$$

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Measuring system

- Sierra Instruments, Cal=Trak SL-800 & SL-800-10, (1.2 – 600) mg/min

- climate chamber (22 °C)
- MFCs
- 3-way valves with pneumatic actuator
- bellows & spirit level
- camera

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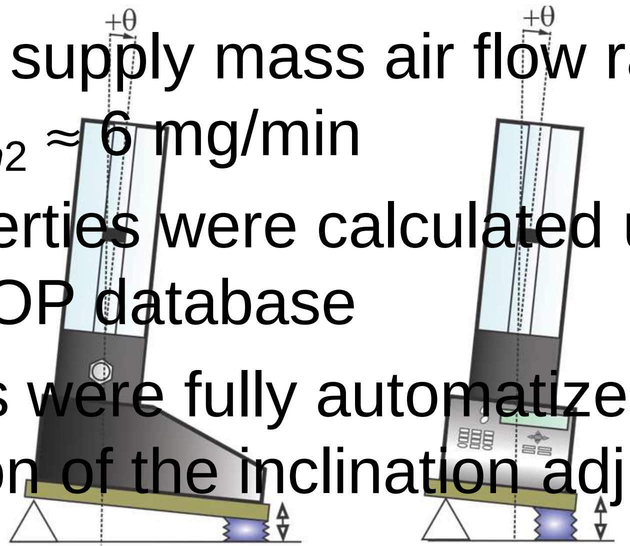
Measuring system

- inclination in both directions is changed between: <u>0° → 5° → 0° → –5° → 0°</u>
- nominal supply mass air flow rate: $q_{m1} \approx q_{m2} \approx 6$ mg/min
- air properties were calculated using the REFPROP database
- the tests were fully automatized, with the exception of the inclination adjustment



back-forth   left-right

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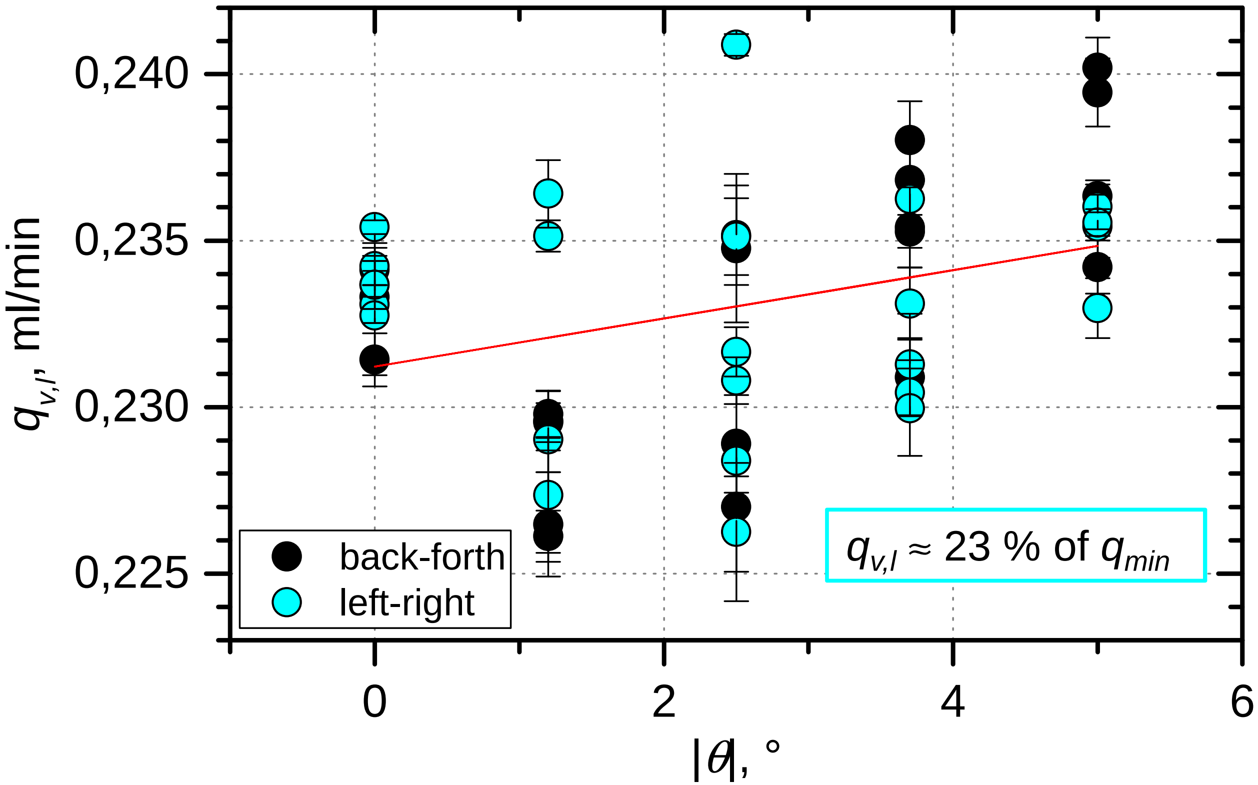
Results



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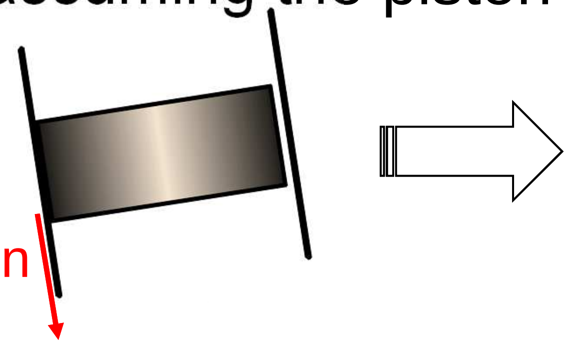
Results

- small variations of measured leakage flow rates → path of the piston remains similar
- assuming the piston touches the wall



increased pressure difference

$$\frac{\Delta p_\theta}{\Delta p_0} = \cos|\theta| + k_f \sin|\theta|$$

- **idea**: relate leakage flow rate with pressure inside the flow cell

$$p = \frac{1}{M}\sum_{i=1}^{M}\frac{p_{1,i} + p_{2,i}}{2}$$

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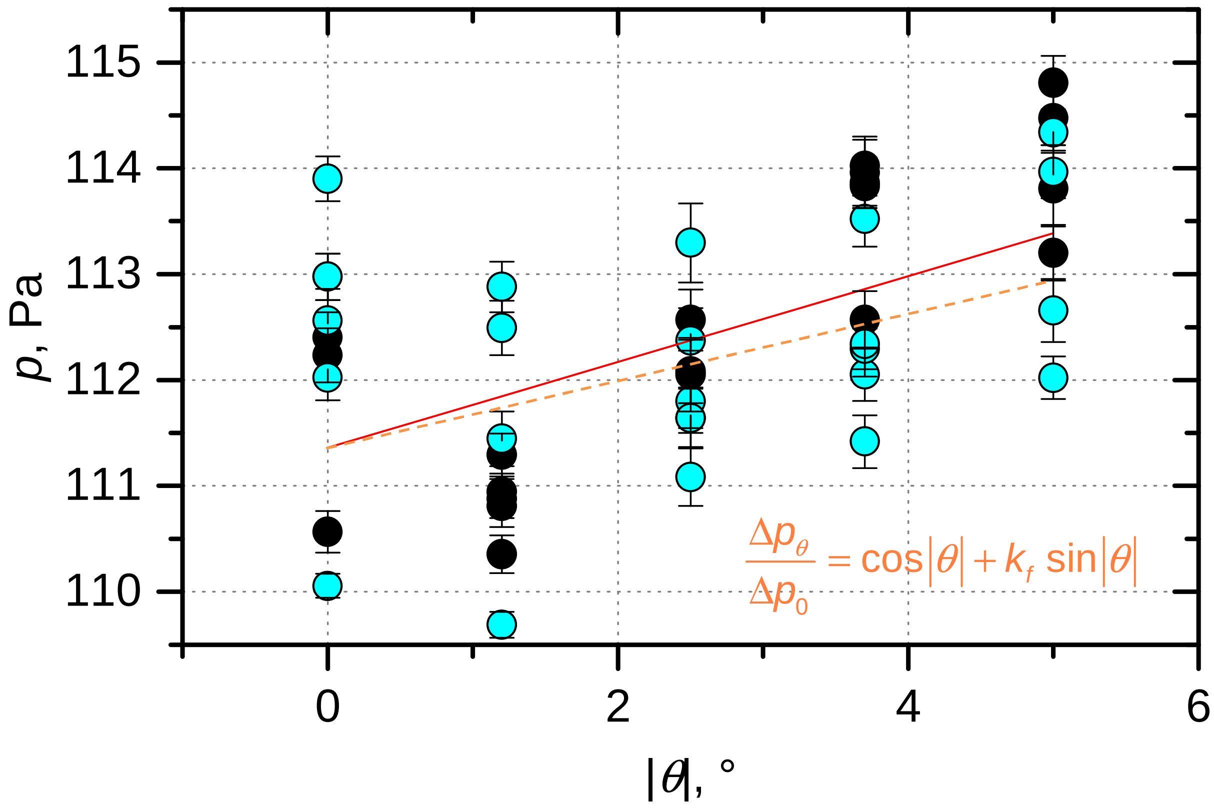
Results



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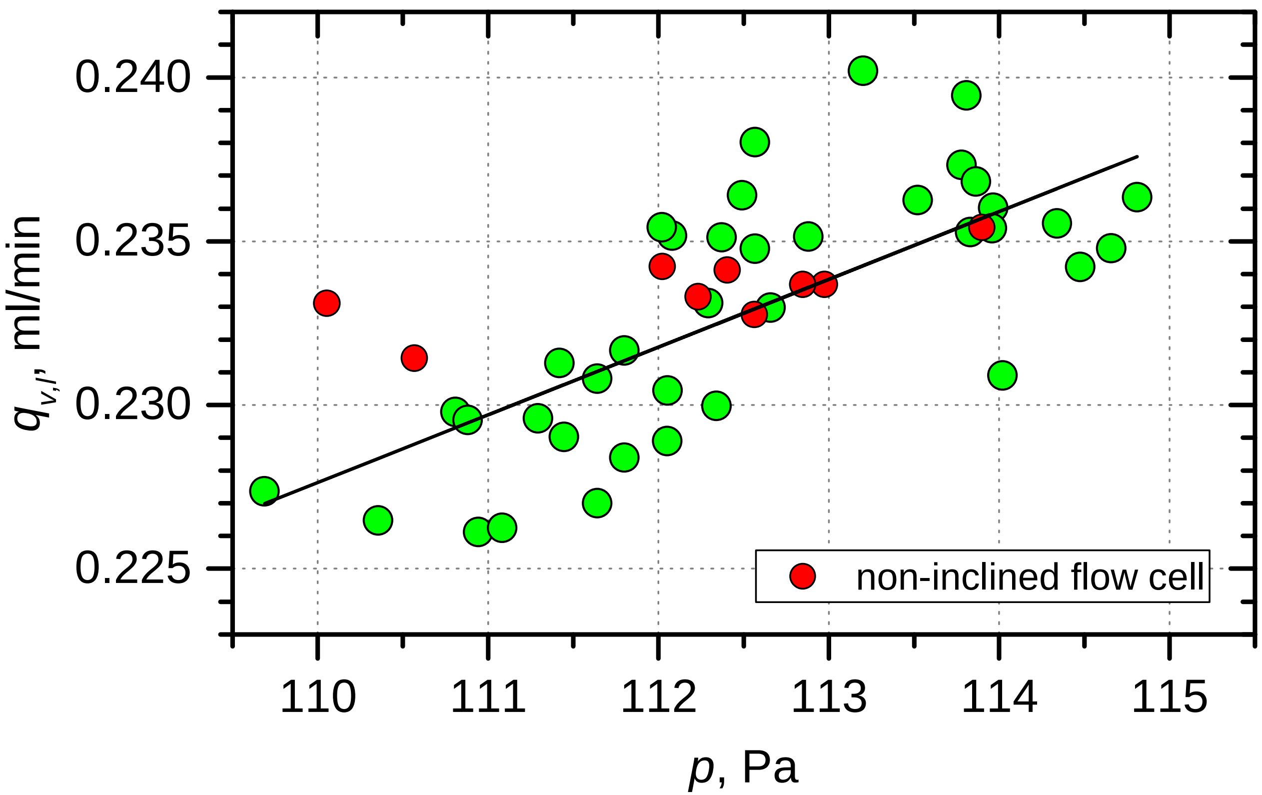
Results



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Conclusions

- piston touches the cylinder wall – it slides along the wall
- leakage flow rate in flow cell is related to the increased friction (pressure)
- main drawback: the pressure is measured only at the beginning and at the end of the stroke
- future plans: expand the study to other two flow cells → general correction model

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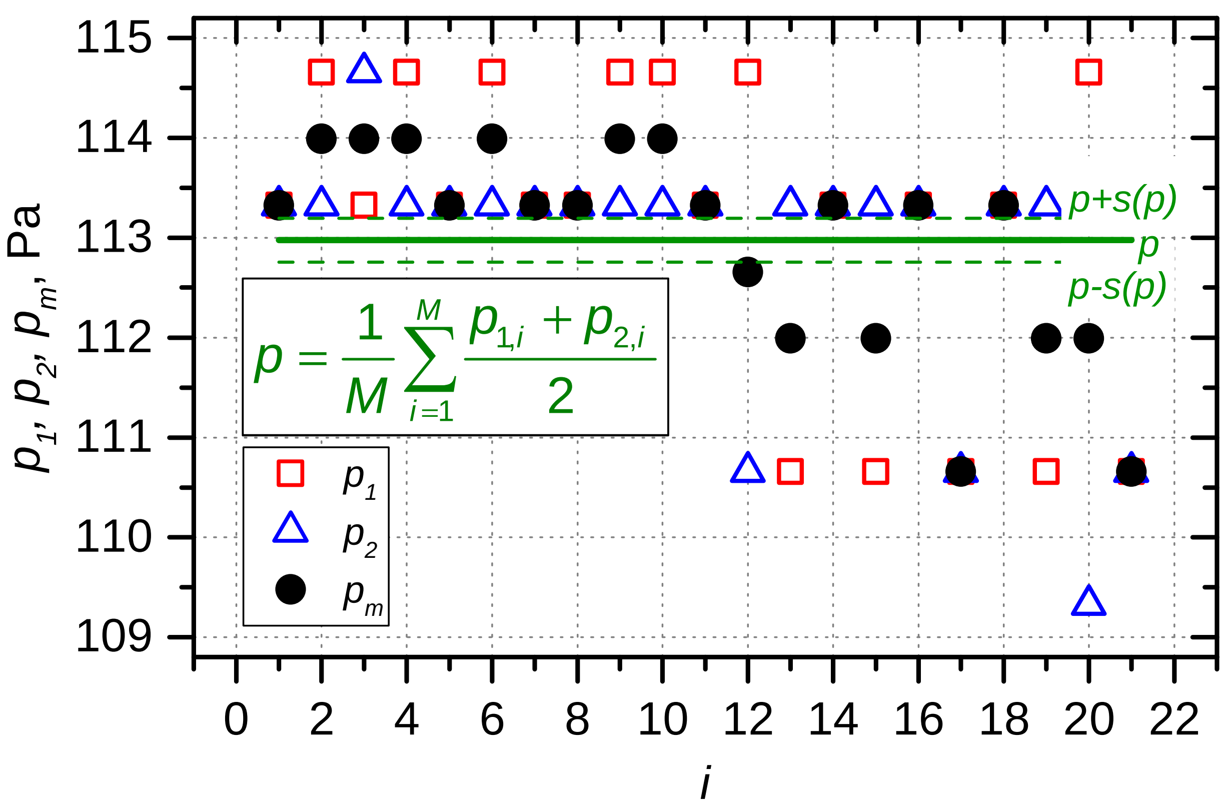
Results



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Results

- integrated sensor measures pressure at the beginning (p_1) and the end (p_2) of the stroke
- characteristic pressure: $p = \frac{1}{M}\sum_{i=1}^{M}\frac{p_{1,i}+p_{2,i}}{2}$
- experiments proved that p_1 and p_2 are independent of the flow rate $\rightarrow$ important, because mass flow rate through the meter changes during tests

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Results