EURAMET TRAINING ON HYDRAULIC PRESSURE BALANCES

FEBRUARY 2017

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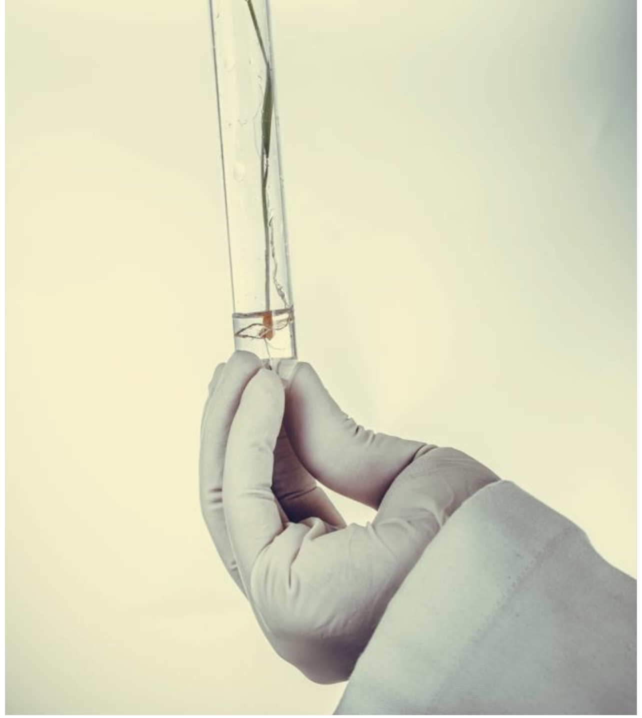
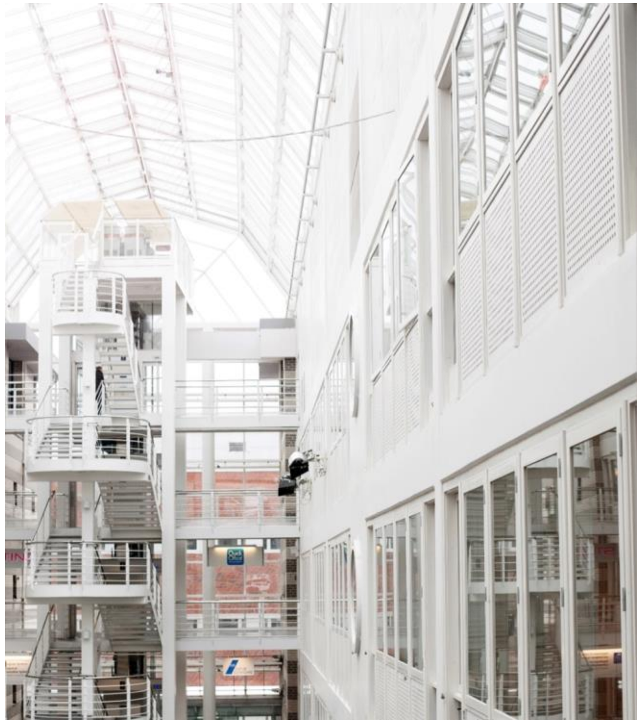
Research Institutes of Sweden

RISE Safety and Transport

Measurement Technology





Programme 27 February 2017

Registration of the participants, opening and welcome

Basic theory

Working principle of pressure balances including

- basic principles
- different piston/cylinder designs
- other considerations on the use of pressure balances.

Guidance literature including standards and guidelines

Short presentation of available literature in the area including guidelines.

Programme 28 February – 1 Mars 2017

Practical training of using a pressure balance

- cleaning techniques
- practical considerations on the use of pressure balances
- hints how to judge the performance

Presentation of the formulas used for calculation of generated pressure

Calculations of pressure generated by the pressure balance

Uncertainty calculations.

Cross-floating techniques when calibrating a pressure balance.

Practical exercises

Different calculation principles

Practical hints

- I like discussions, interrupt whenever you don't agree/understand or want to clarify something

- Coffee breaks (Or tea, at least for me if I can choose)

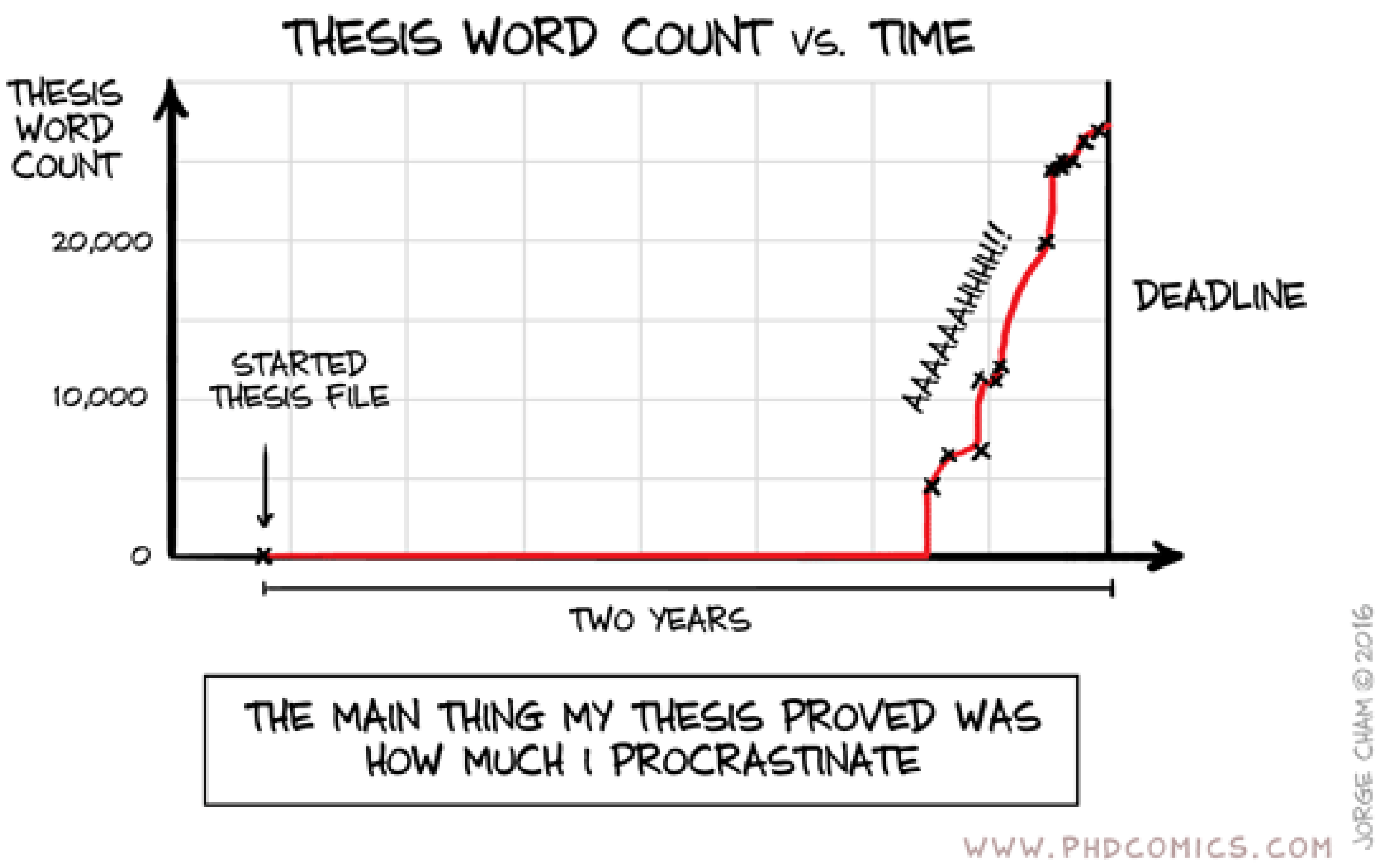
- Lunch breaks

- Facilities

No matter what the historians claim,

"BC" really stands for "**B**efore **C**offee"

Cherise Sinclair



THESIS WORD COUNT vs. TIME
THESIS WORD COUNT
20,000
10,000
0
STARTED THESIS FILE
AAAAAAAHHHH!!
DEADLINE
TWO YEARS
THE MAIN THING MY THESIS PROVED WAS HOW MUCH I PROCRASTINATE
WWW.PHDCOMICS.COM
JORGE CHAM © 2016

Presentations

In short:

Who are you?

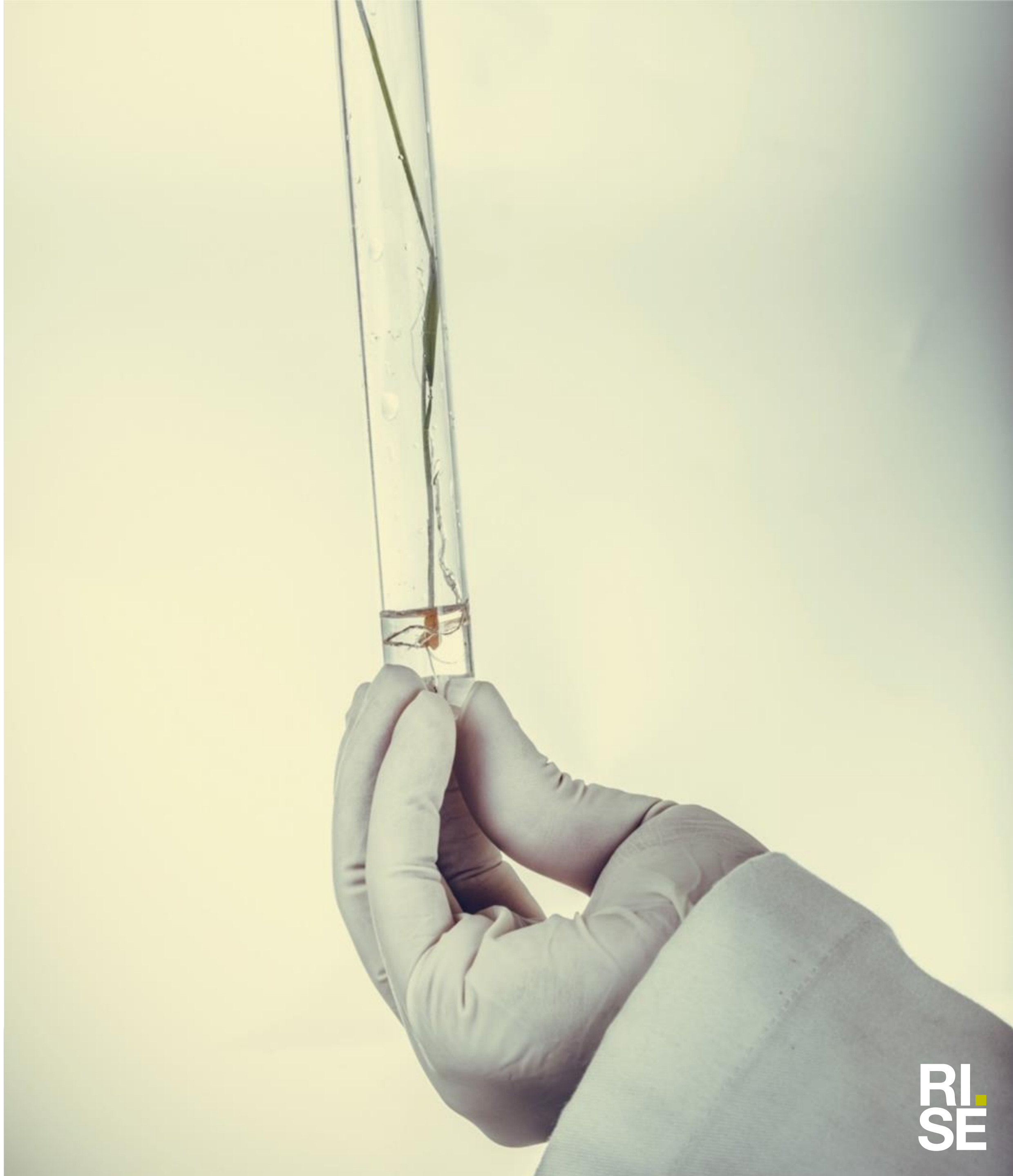
Why are you here?

What do you expect from these days?

RISE Mission from the Swedish Government

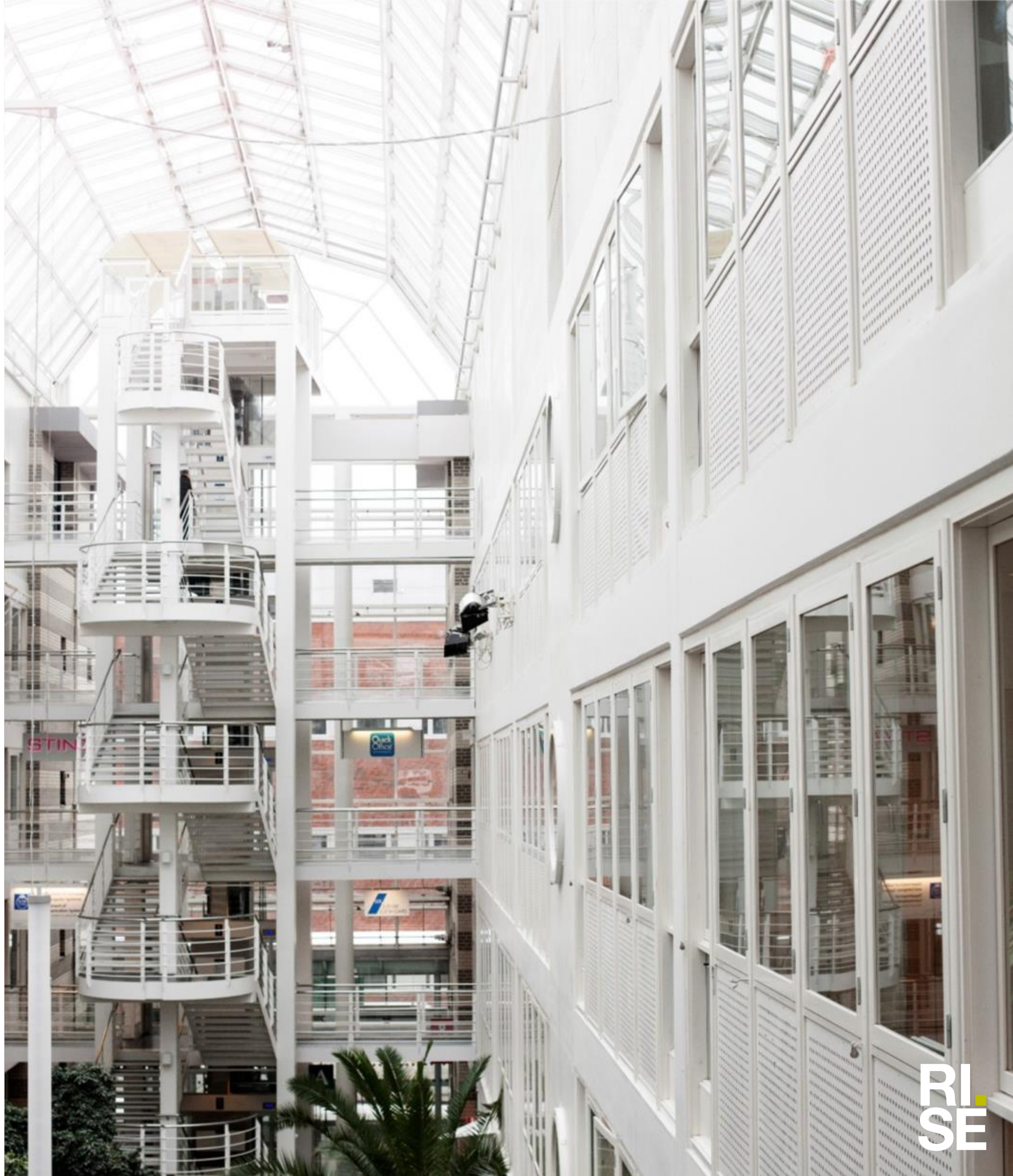
- ” Collaborate closely with academia and industry to advance excellence in strategically important areas, and in doing so help accelerate transformation within the business world.”
- “Develop and increase the use of our leading, dynamic environment for testing, demonstration and pilot production.”
- "Support and encourage organizations - particularly small and medium-sized enterprises - to participate in EU research programmes and benefit from international collaborative research."

Excerpts from the Research Proposition 2016/17: 50 (Kunskap i samverkan).



We are building **one** strong, **unified,** institute for Sweden

- Sweden needs a strong national innovation capacity to meet international competition, in support of our welfare and to meet global grand challenges.
- The new RISE aims to build a stronger Swedish institute sector that will actively support Swedish industry that provides increased benefit for industry and society.

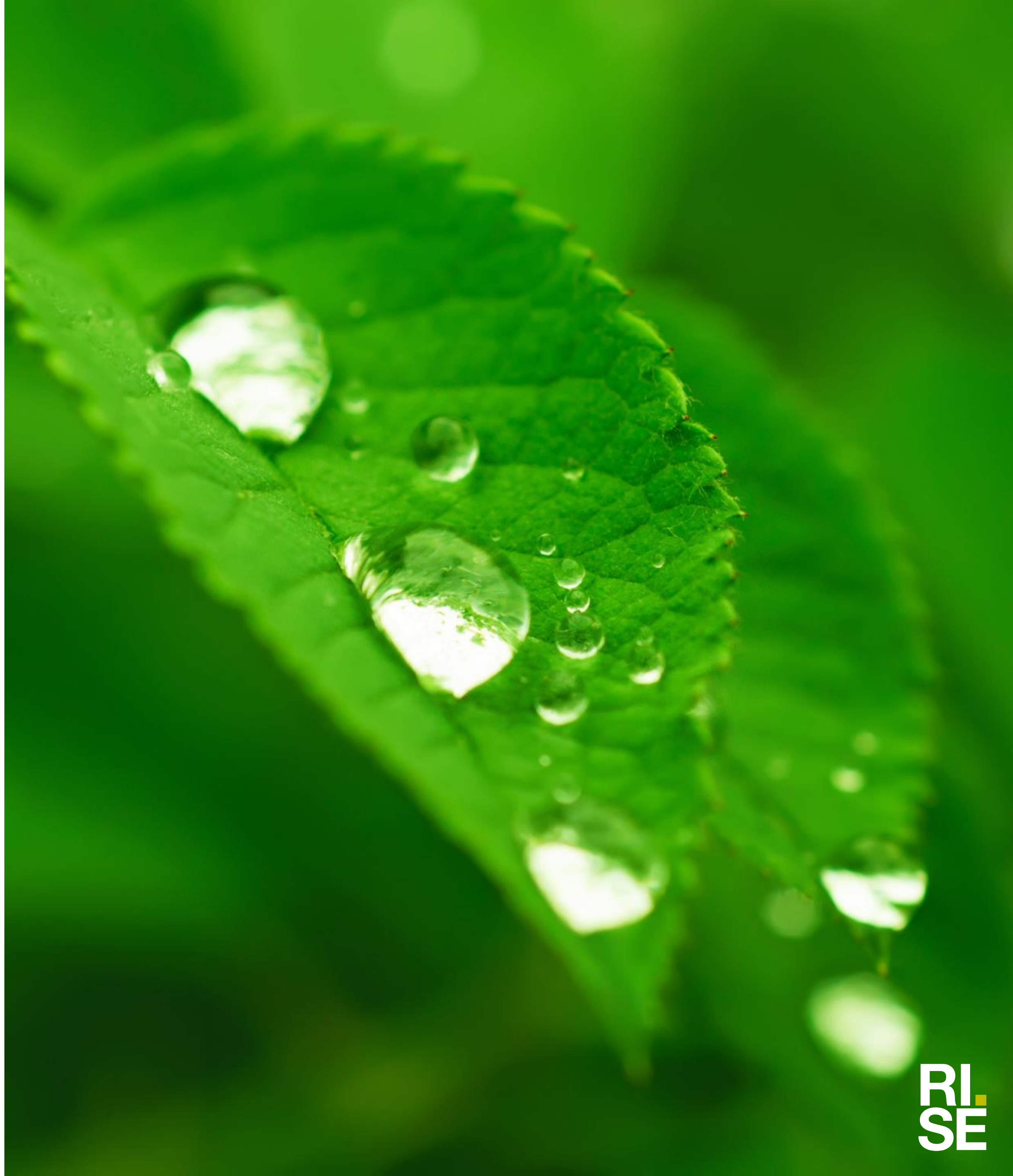


Three have become one - RISE

The RISE institutes Innventia, SP and Swedish ICT have merged in order to become a stronger research and innovation partner for businesses and society.

As the united **RISE we will**

- Increase both our own and our partners international presence and competitiveness
- Strengthen regional industry clusters
- Create powerful innovation infrastructure for industry and society
- Support the creation of innovative, sustainable solutions to global grand challenges
- Support SMEs across the whole of Sweden



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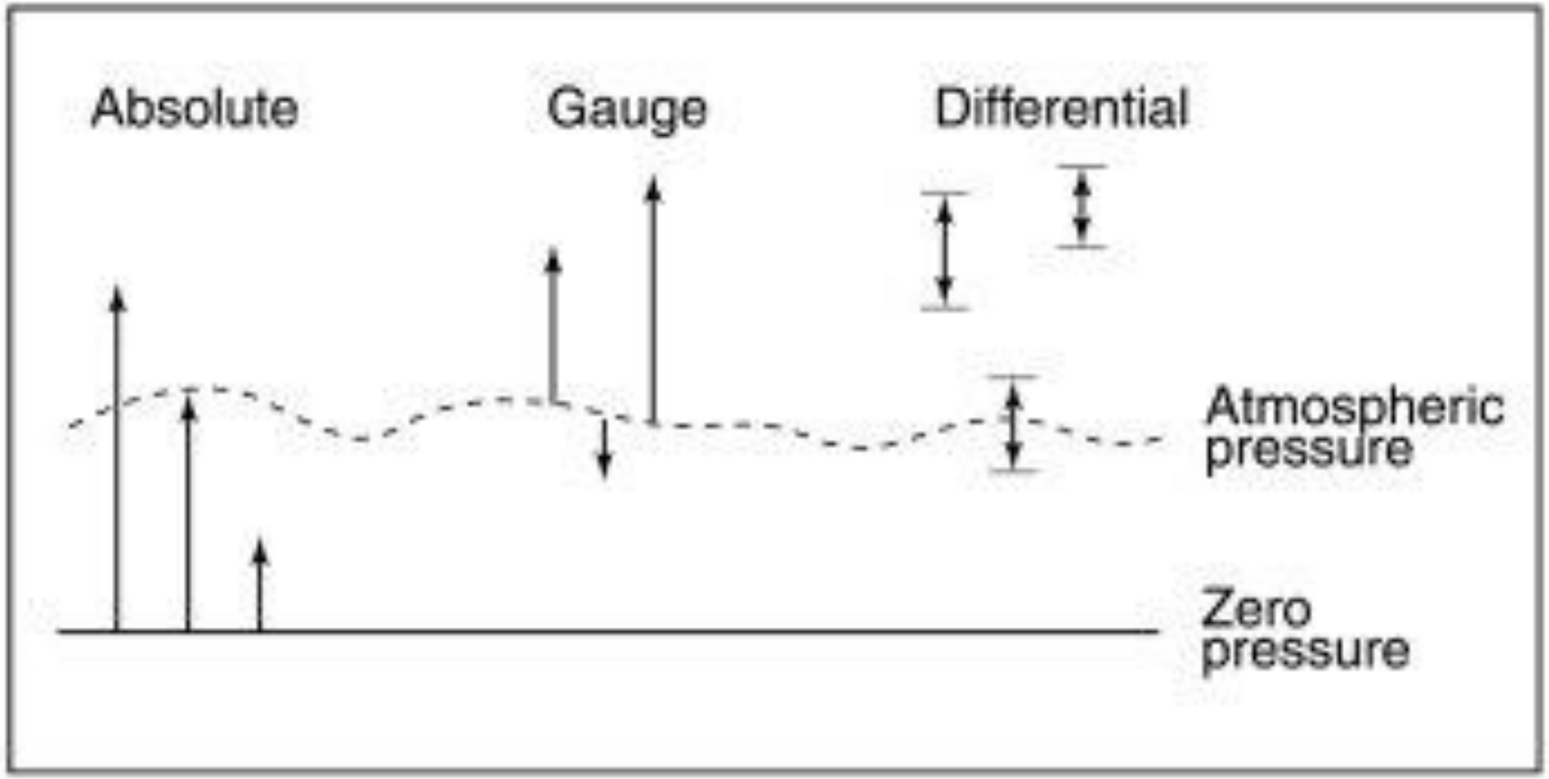
Our **vision**

An internationally leading partner for innovation

Pressure modes

Absolute pressure: Zero level at “total emptiness

Gauge pressure: Zero level at atmospheric pressure



Differential pressure: Pressure difference over a restriction or similar, arbitrary chosen reference level.

Pressure basics

Pressure

$$\Delta p = \frac{m * g}{A}$$

$$\Delta p = \rho * g * \Delta h$$

How big is 1 Pascal???

Liquid manometer

Based on general physical principles

Simple principle

Differential or absolute

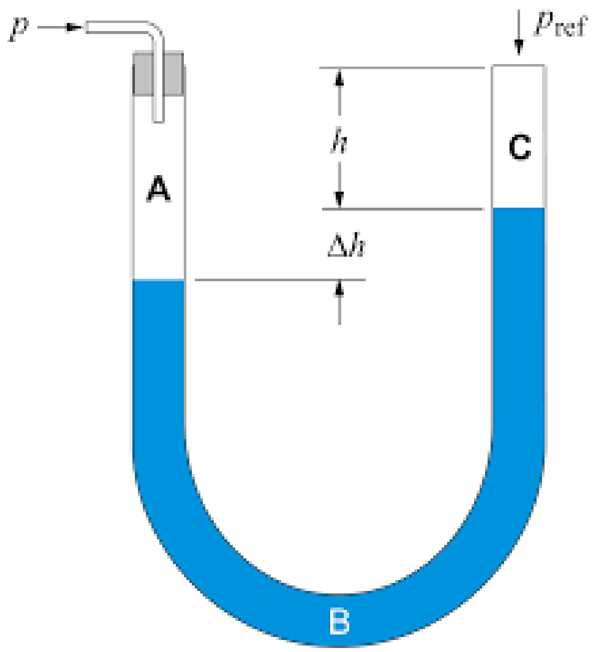
Hard to operate

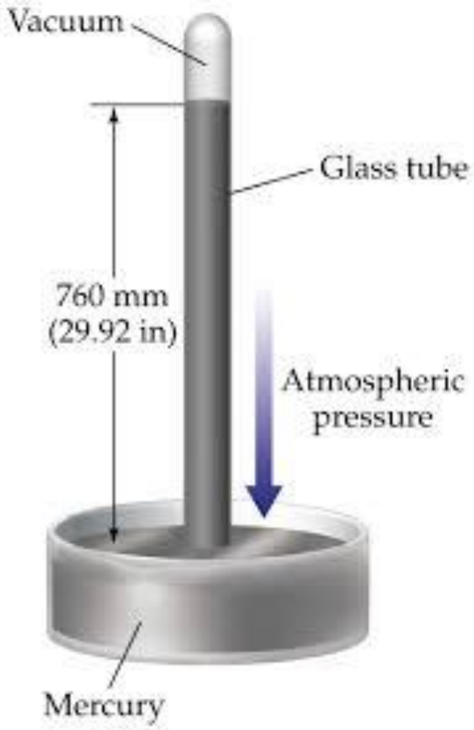
Long stabilisation times

Temperature depending

…

$$\Delta p = \rho * g * \Delta h$$

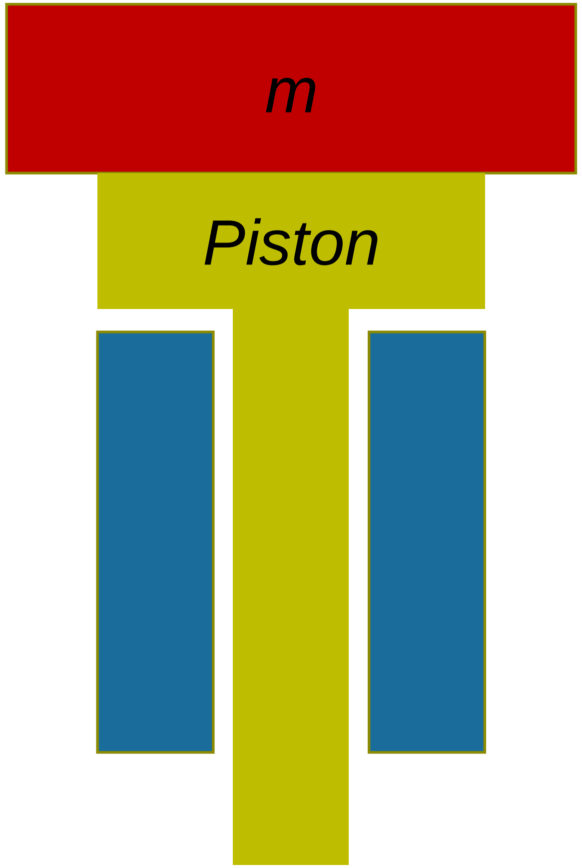




Pressure balance

Simple basic relation:

$$\Delta p = \frac{m * g}{A}$$



Δp: Pressure needed to raise piston with masses

m: Total mass of piston and masses applied to the piston

g: Local gravity

Pressure balance

$$\Delta p = \rho * g * \Delta h$$

Many different names

- Pressure balance
- Deadweight tester
- Piston gauge
- …

What's the difference?

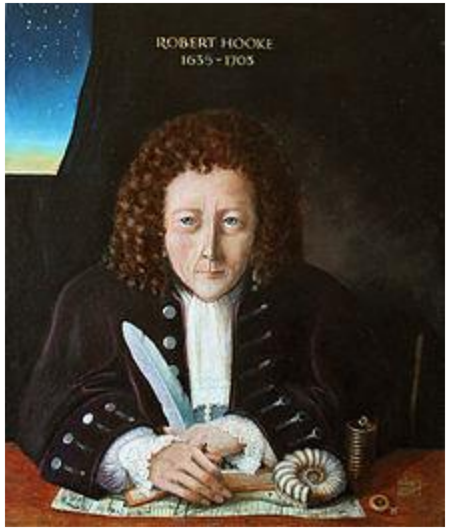
Some basic principles that might affect our measurements

Archimedes

Hooke

Young

…

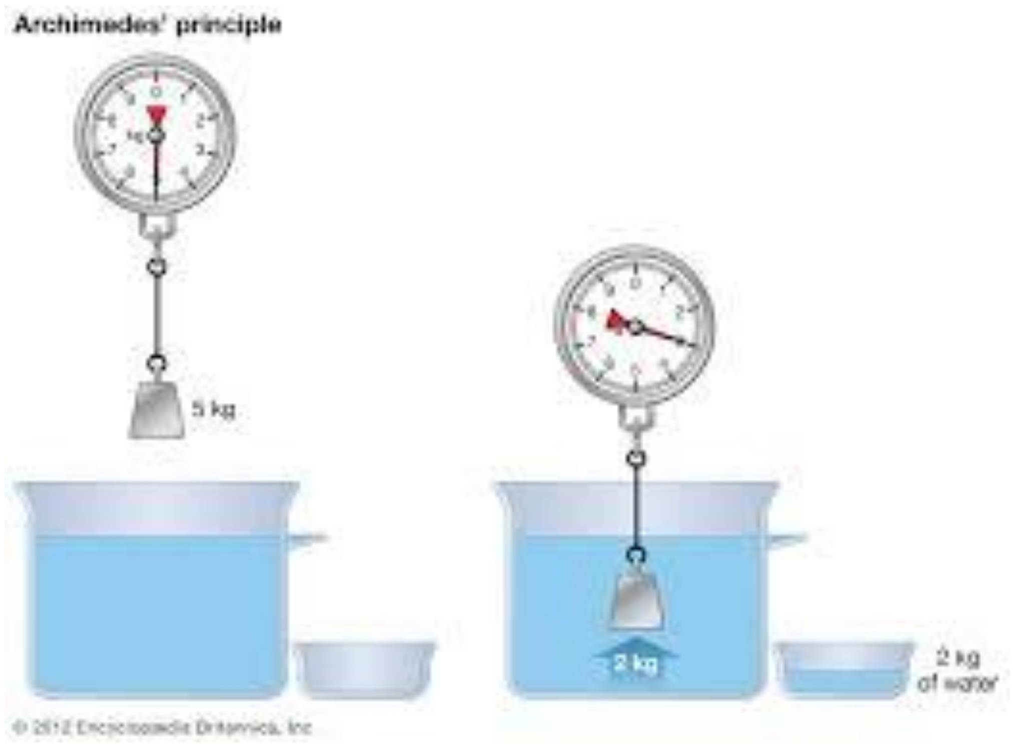


Archimedes principle

Any floating object displaces its own weight of fluid.

— Archimedes of Syracuse

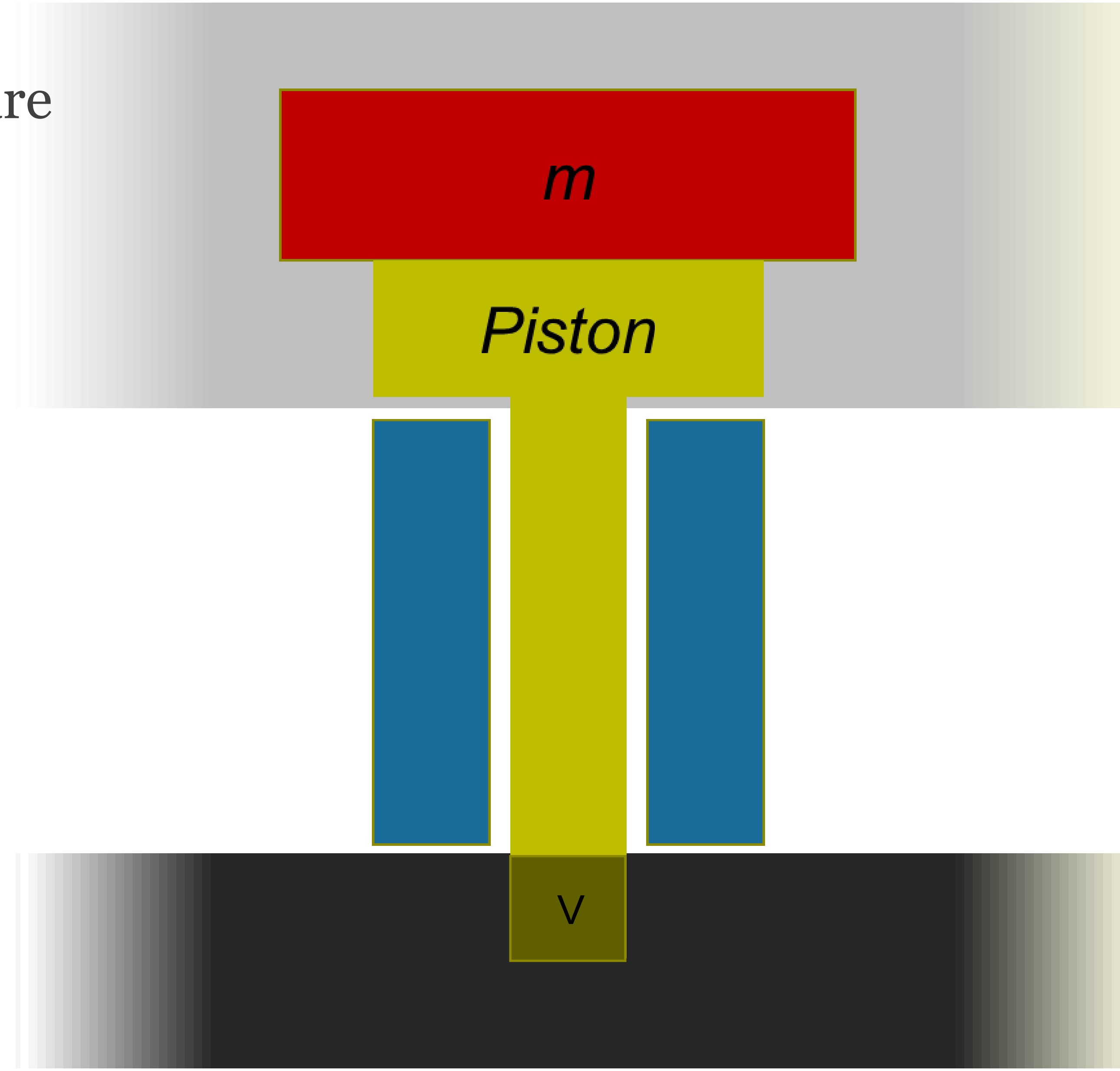
What's that to do with our pressure measurements???



Archimedes principle (again)

Our masses are surrounded by air, they are floating in the sea of air.

For accurate measurements we have to consider this effect.



Also, part of the piston may be submerged in the pressure media, resulting in an upward force. This depends on the design of the pressure balance

Pressure deformation of piston and cylinder

Pressure dependant geometry

Due to pressure forces the piston will shrink and the cylinder will expand

- Depending on material used
- Also depending on geometry
- … and mounting torque

- Hooke’s law
- Young’s modulus
- . and more

… and temperature

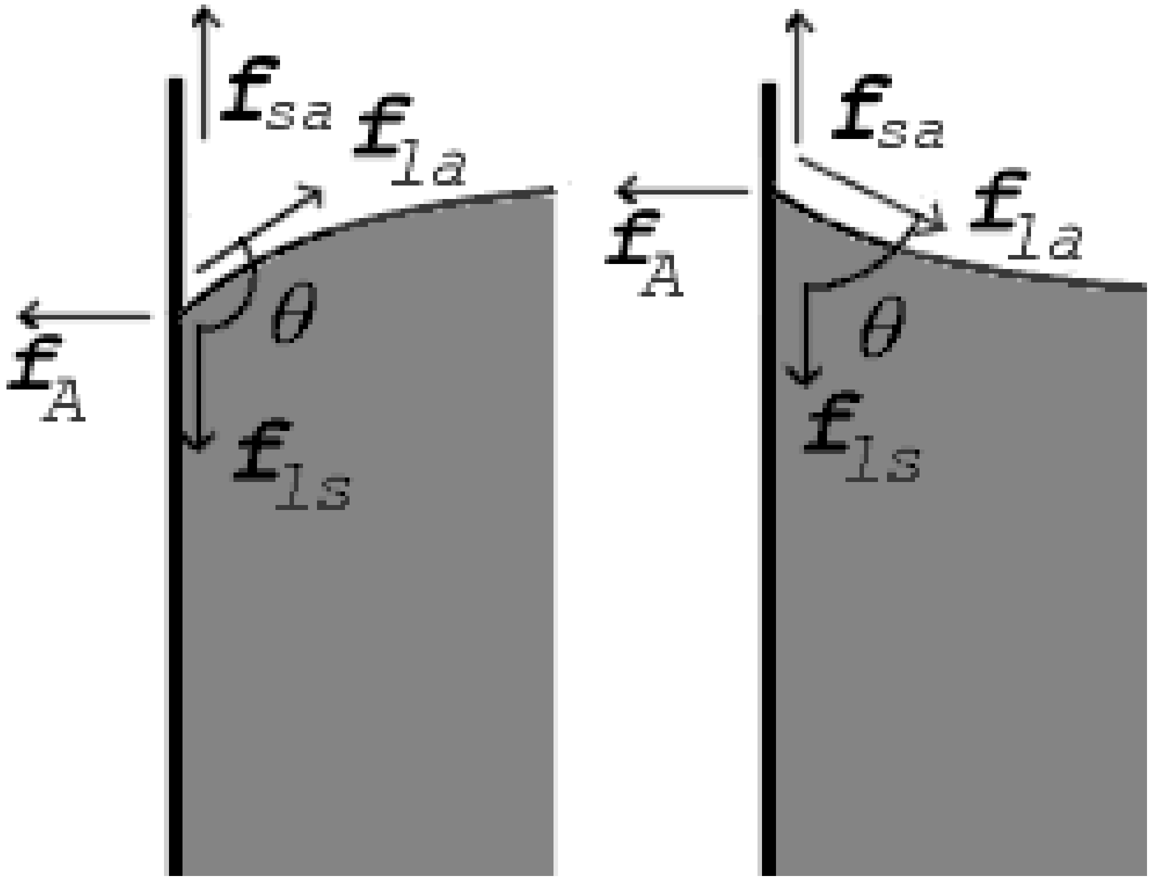
- Metal geometries changes with temperature
- The effect is linear in the range used
- The size of the effect is material-dependant
- It is used as a correction factor for the effective area
- Nominal area given at 20 °C

Surface tension

For liquid pressure balances, we also have to consider surface tension.

This gives also a additional force on the piston

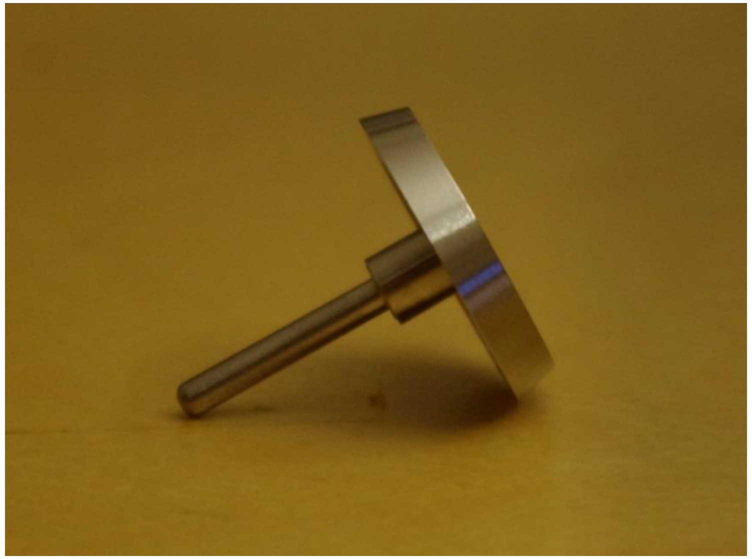
Depending on the medium used and the circumference of the piston.

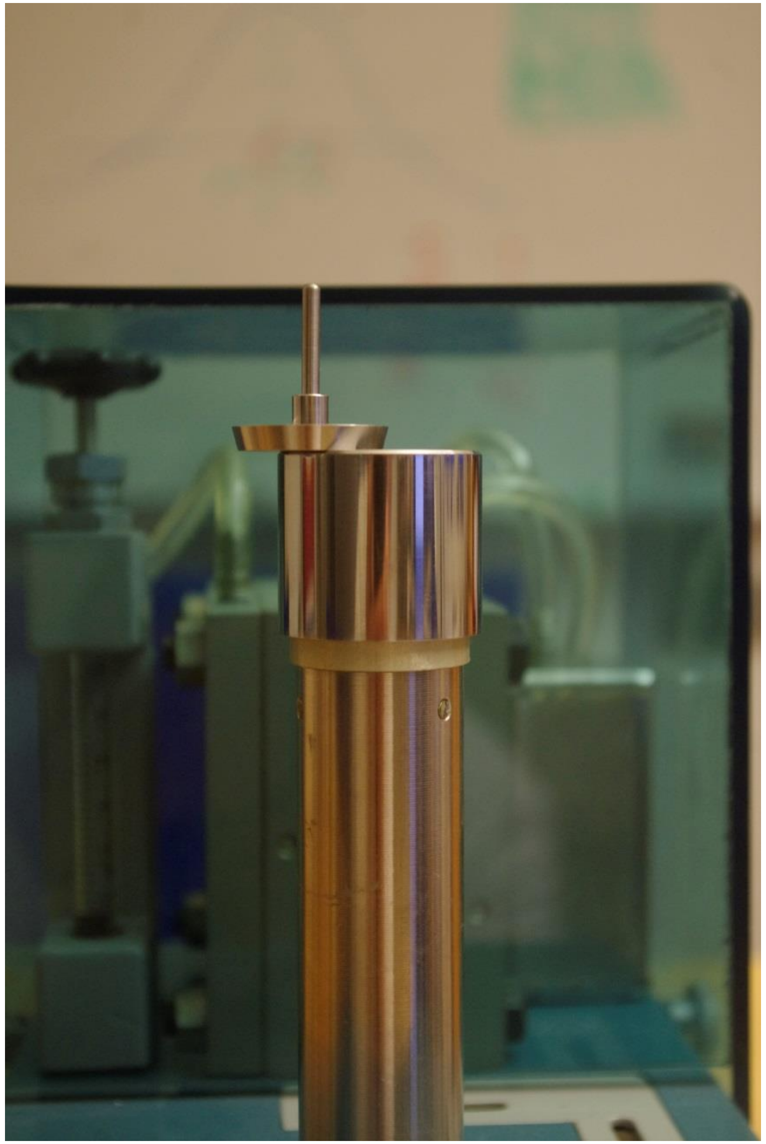


Different design of p/c units

- Free deformation
- Re-entrant design
- Controlled clearance

… other designs exist but are not covered here



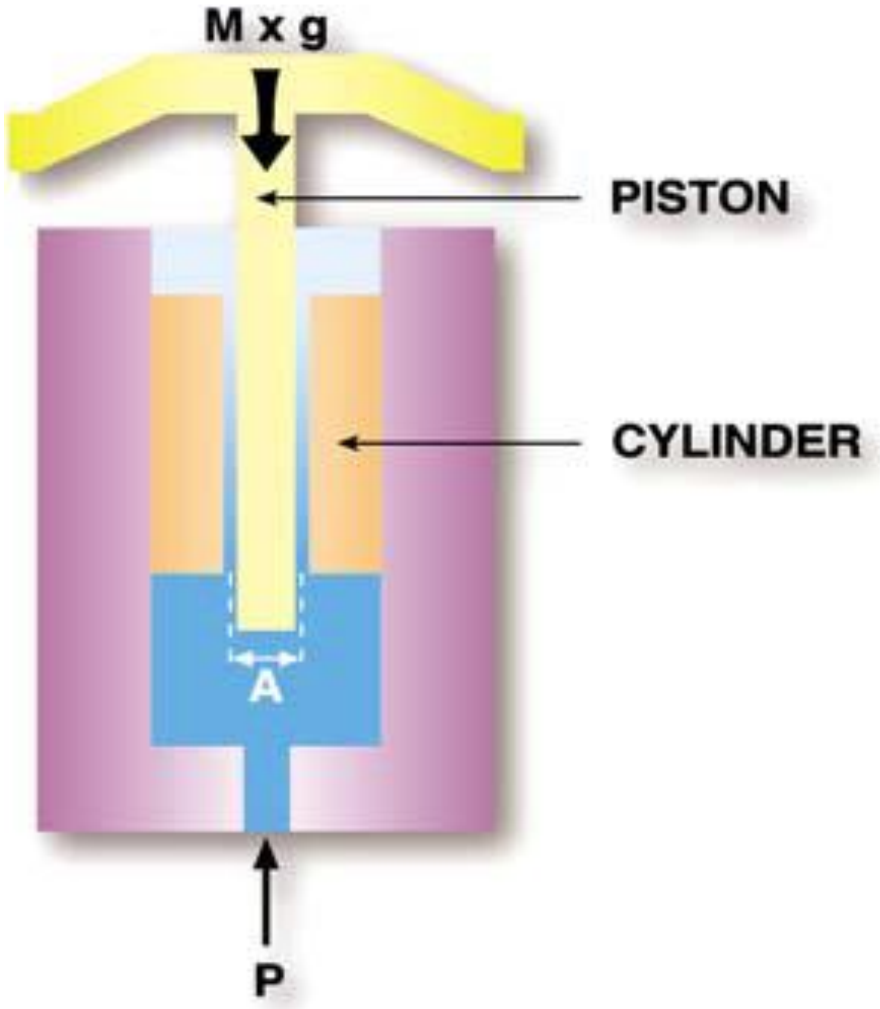


Free deformation

Simple

Most common

+ Linear pressure drop
+ Calculable deformation coefficient
+ Reduction of bottom end loading
- Deformation influenced by torque in mounting nut

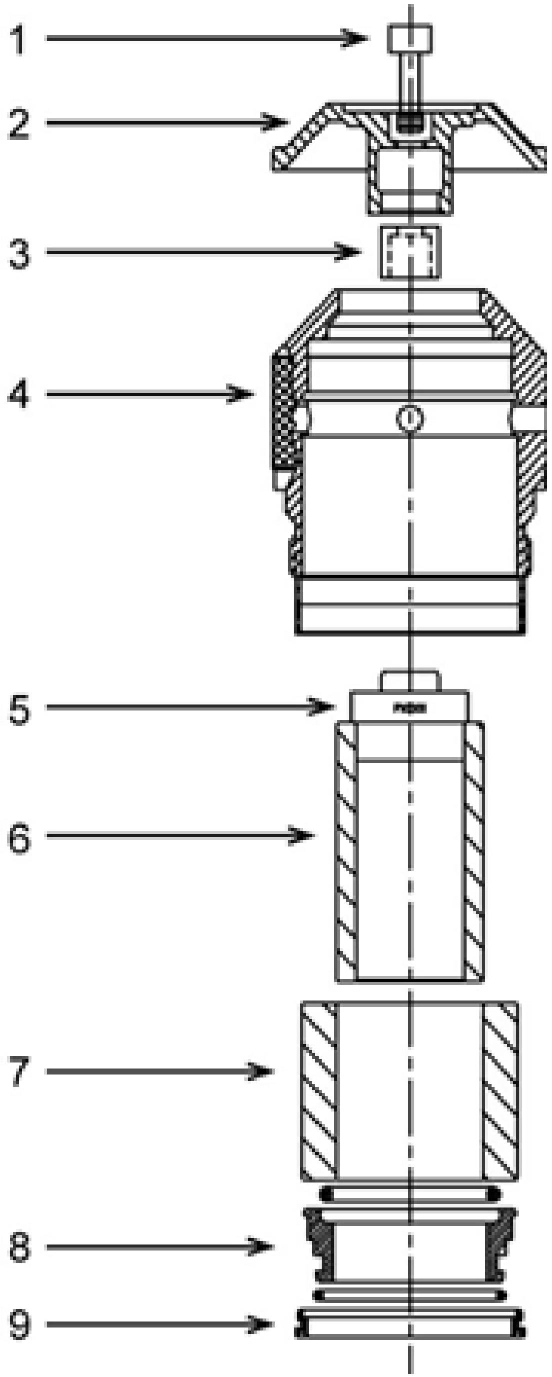


From Fluke.com

Inverted free deformation

Same basic principle as for free deformation but with floating cylinder instead

Today mostly used for large area p/c units



Re-entrant design

+ Minimizes gap
+ Limits deformation for material with low Young's module
+ Reduces drop rate
- Deformation influenced by torque in mounting nut
- Pressure drop in gap is concentrated at the bottom
- Sudden stress changes on the cylinder wall
- Deformation coefficient difficult to predict

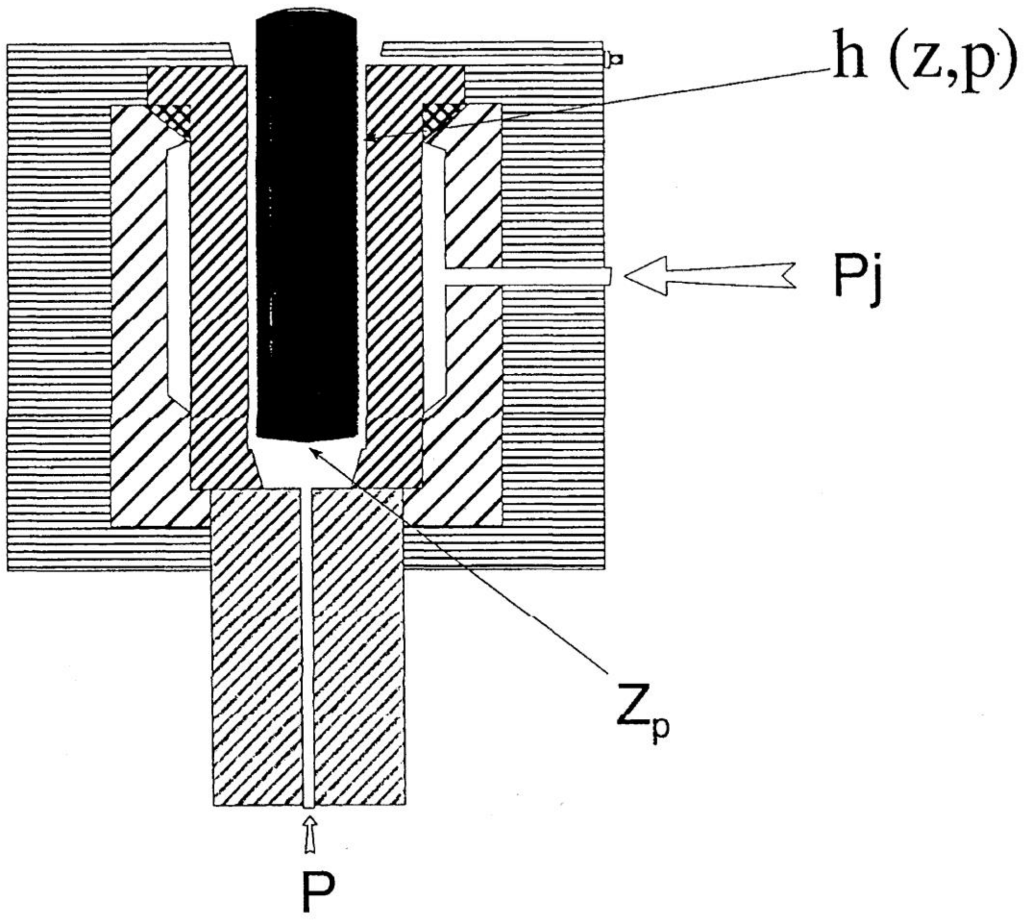
Controlled clearance p/c design

Active control of the gap between the piston and cylinder.

By setting a suitable jacket pressure, P_j, the clearance can be controlled.

Normally used for keeping the fall rate constant

Almost impossible to model.



Primary and secondary standards

Primary standards – first in the chain – base for the quantity

Secondary standards – reference standards that “inherits” their properties from a calibration against a better reference.

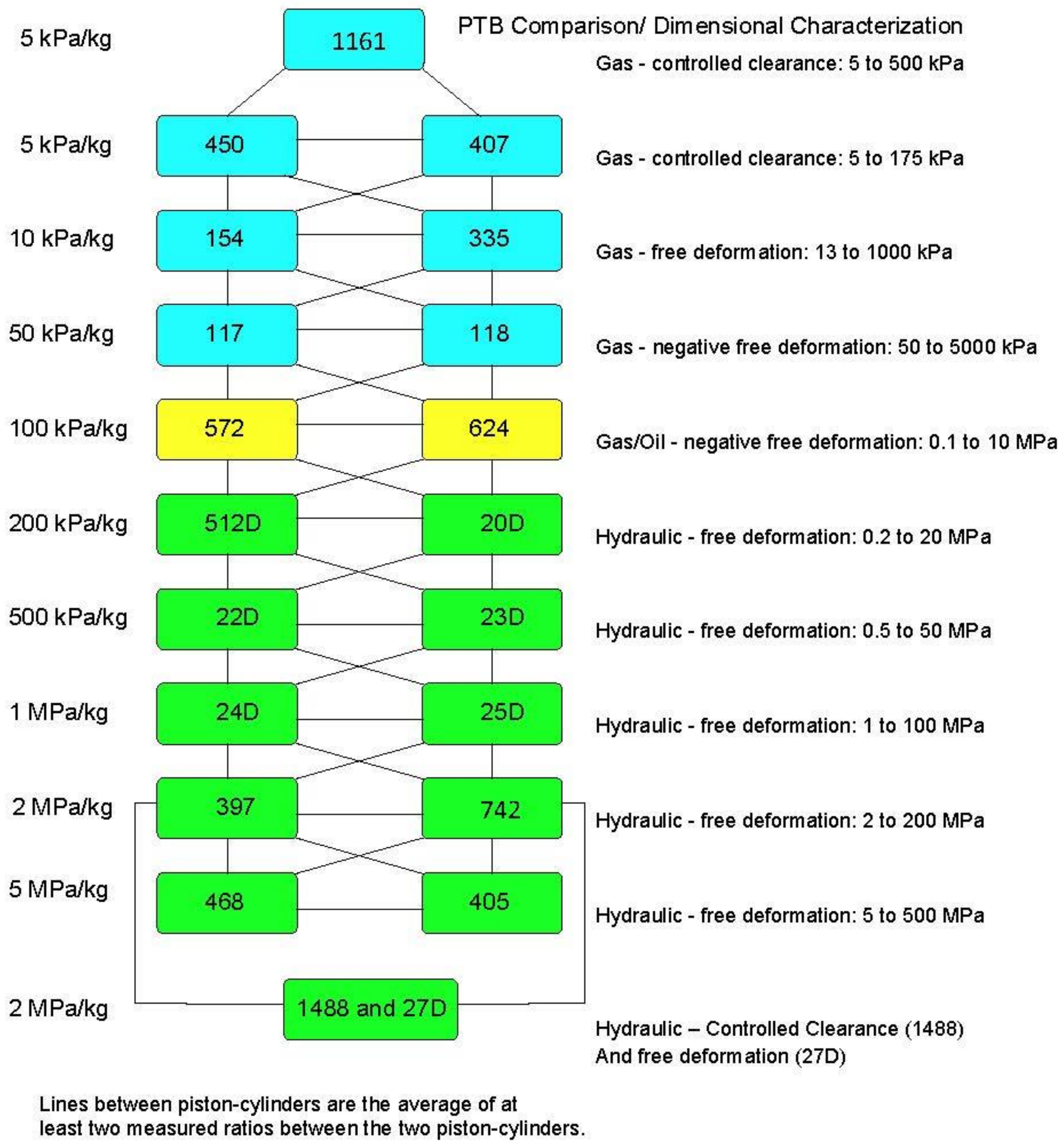
Most pressure balances are secondary standards

Primary standards in pressure are:

- Liquid manometers (U>5ppm)
- Large area pressure balances whose effective area have been determined geometrically (U>1ppm).

Traceability chain

Starting off with a large are p/c unit
Modelling the deformation of each unit



Once again, basic equation

$$\Delta p = \frac{m * g}{A}$$

This is not enough, what more to consider?

Measurement equation

We started with:

$$\Delta p = \frac{m * g}{A}$$

Have to consider:

- Temperature effects
- Deformation
- Archimedes
- Surface tension
- …

$$p_e = \frac{\sum_i m_i * g * \left(1 - \frac{\rho_a}{\rho_{mi}}\right) + \sigma * c}{A_0 * (1 + \lambda * p) * \left[1 + \left(\alpha_p + \alpha_c\right) * (t - t_r)\right]}$$

Measurement equation

$$p_e = \frac{\sum_i m_i * g * \left(1 - \frac{\rho_a}{\rho_{mi}}\right) + \sigma * c}{A_0 * (1 + \lambda * p) * \left[1 + \left(\alpha_p + \alpha_c\right) * (t - t_r)\right]}$$

- p_e: applied pressure
- m_i: mass of applied mass I
- g: local gravity
- ρ_a: air density
- ρ_m: mass density
- σ: surface tension of the liquid
- c: circumference of the piston

Measurement equation

$$p_e = \frac{\sum_i m_i * g * \left(1 - \frac{\rho_a}{\rho_{mi}}\right) + \sigma * c}{A_0 * (1 + \lambda * p) * \left[1 + \left(\alpha_p + \alpha_c\right) * (t - t_r)\right]}$$

A_o: Area at zero pressure

λ: pressure deformation coefficient

p: (nominal) pressure

α_p: Temperature coefficient of piston

α_c: Temperature coefficient of cylinder

t: p/c temperature

t_r: reference temperature for A_0

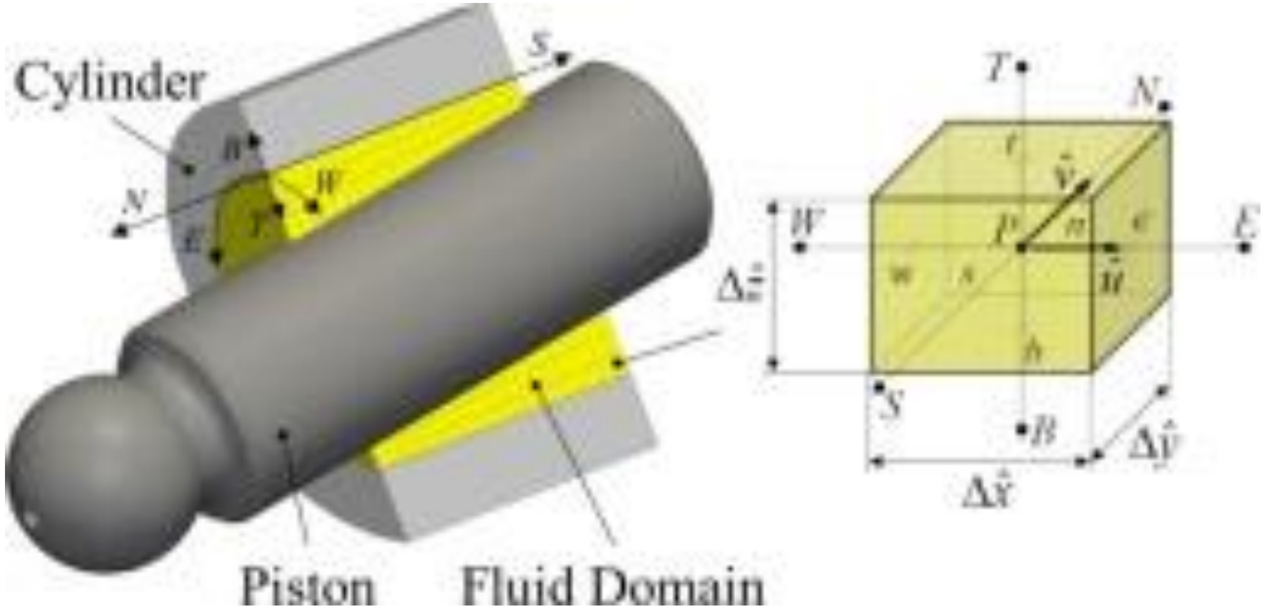
The effect of Viscosity

- Do the viscosity of the Pressure media affect the performance?
- If so, in which way?

- The viscosity changes the fall rate and the sensitivity of the pressure balance
- Low viscosity gives faster fall rate, longer rotation time, more leakage but higher sensitivity
- High viscosity gives long fall rate, short rotation times, less leakage but lower sensitivity

Why rotate the piston?

- **To minimize the friction!** A non-rotating piston will tilt and stick to the sides of the cylinder
- **To monitor performance!** A contaminated piston will not rotate as smooth as a clean one.



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Litterature

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Klingenberg et al, Characterization of a pressure balance from dimensional measurements and from pressure comparison experiments, PTB-Mitteilungen 101 1/91

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Dadson et al, The Pressure Balance, Theory and Practice, NPL 1982 (The brown book)

Sabuga et al, Calculation of the distortion coefficient and associated uncertainty of PTB and LNE 1 GPa pressure balances using finite element analysis – EUROMET project 463. Metrologia, 2005, 42, pp. 202-206

Metrologia Volume 42, Number 6, December 2005, Special issue: the 4th CCM international conference on pressure metrology from ultra-high vacuum to very high pressures (10^{-9} Pa to 10^{9} Pa)

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EURAMET cg-3, Calibration of Pressure Balances

EURAMET Project 1125, Evaluation of cross-float measurements with pressure balances, Draft C 2011

THANK YOU

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