FAKULTA STROJNÍ TUL

Measurement techniques of pressure, velocity and flow rate

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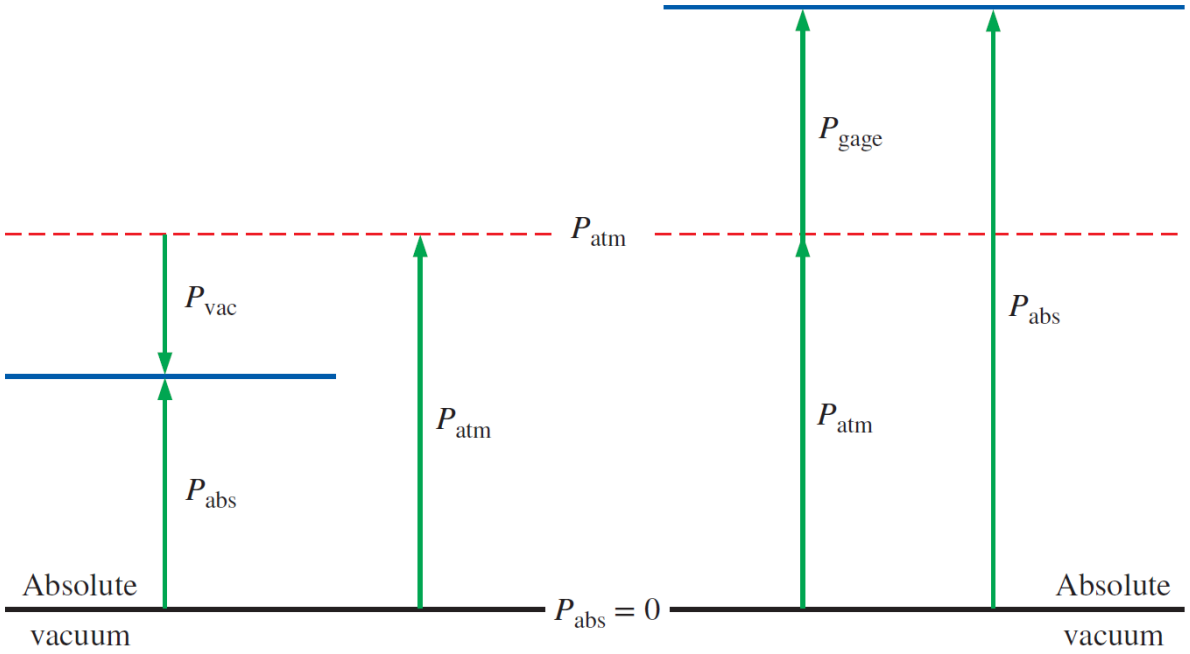
Fundamental principles of pressure measurement

Relative pressure (gage, vacuum), absolute pressure, barometric (atmospheric) pressure



Fundamental definitions of pressure

Pressure defined by means of basic SI units and hydrostatic pressure definition

$$p = \frac{F}{S} = \frac{mg}{L^2}$$

$$(Pa) = \frac{(N)}{(m^2)} = \frac{(kg)\left(\frac{m}{s^2}\right)}{(m)(m)} = \frac{(kg)}{(m)(s^2)}$$

$$p = h\rho g$$

$$(Pa) = (m)\left(\frac{kg}{m^3}\right)\left(\frac{m}{s^2}\right) = \frac{(kg)}{(m)(s^2)}$$

Fundamental definitions of pressure for moving fluid

Total pressure, static pressure, dynamic pressure, velocity

$$p_{total} = p_{stat} + p_{dyn}$$

$$p_{dyn} = \frac{1}{2}\rho v^2$$

Basic classification of devices for pressure measurement

- Manometers filled with a fluid (hydrostatic gages)
    1. Bell-type manometers (the stroke of the bell is proportional to pressure)
    2. Piston-type manometers, e.g., dead-weight testers (Pascal‘s law)
    3. Column-type manometers (weight of a liquid column)

- Mechanical gages or manometers (strain of a flexible element)
    1. Bourdon-type gages (Bourdon tube)
    2. Bellows-type gages
    3. Diaphragm-type gages

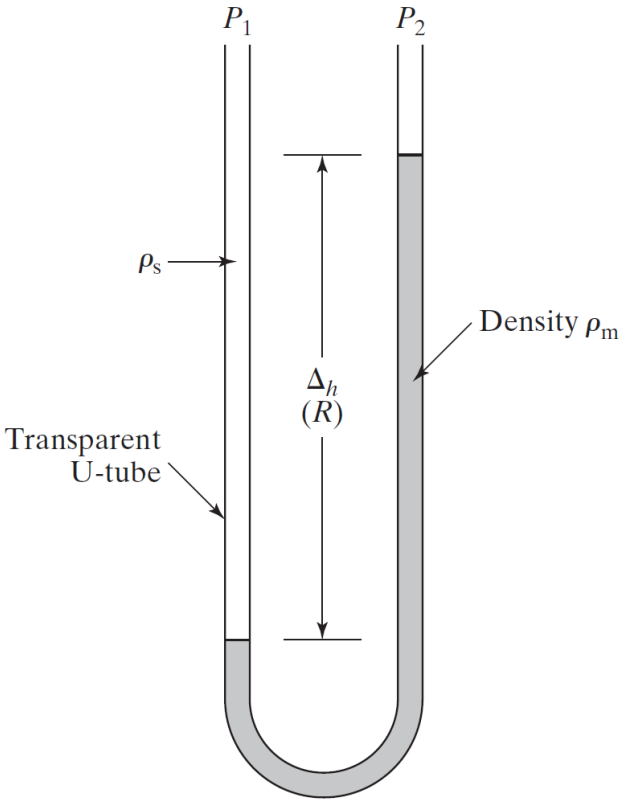
- Pressure transducers (a change of an electrical quantity)
    1. Strain-gage pressure transducers
    2. Capacitive pressure transducers
    3. Piezoelectric pressure transducers
    4. LVDT pressure transducers

Basic classification of devices for vacuum pressure measurement

- Compression vaccum gage (hydrostatic, mechanical, used for calibration)
- Thermal conductivity vacuum gage (thermal conductivity is proportional to the gas pressure, electrical output)
- Ionization vacuum gage (the rate of ionization of the gas is proportional to its pressure, electrical output)

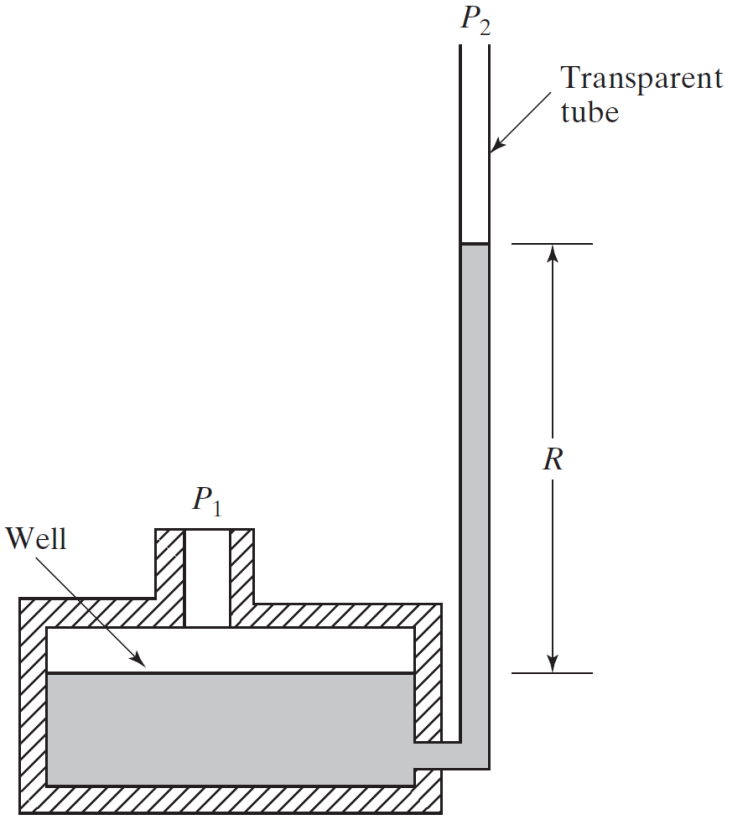
Pressure measurement

U-tube manometer



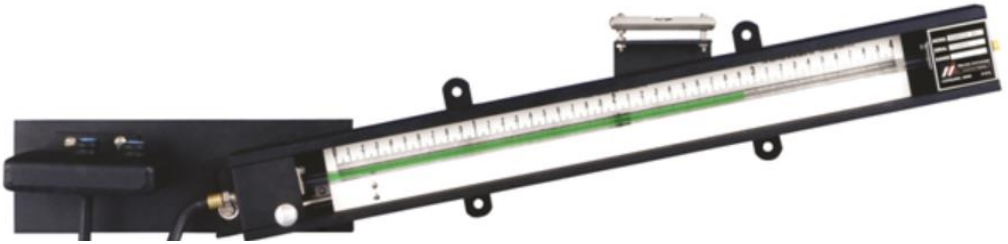
Pressure measurement

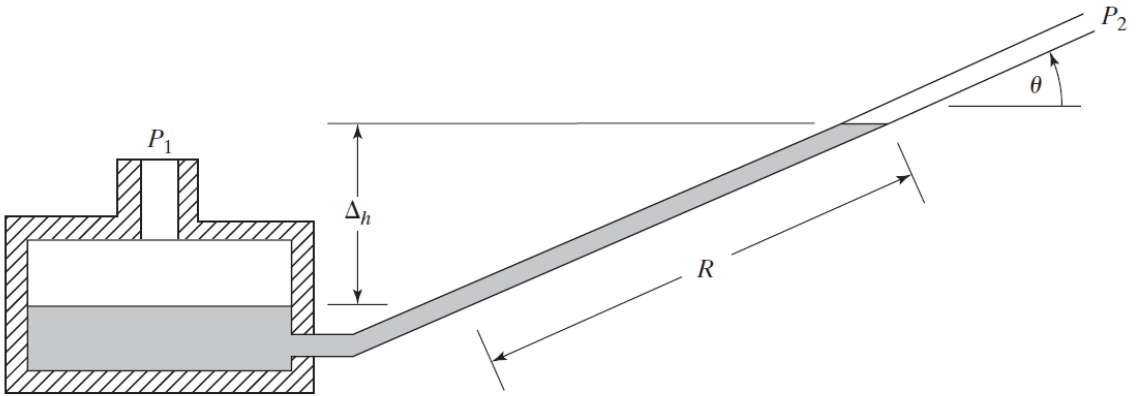
Well manometer



Pressure measurement

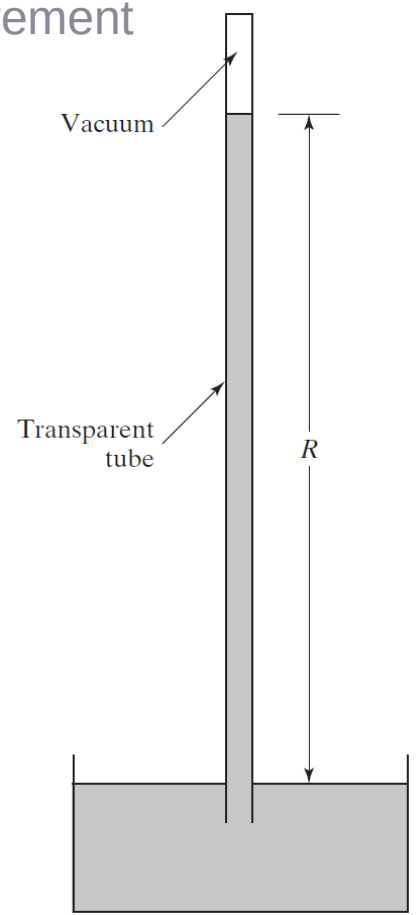
Inclined manometer (range setup, higher accuracy)





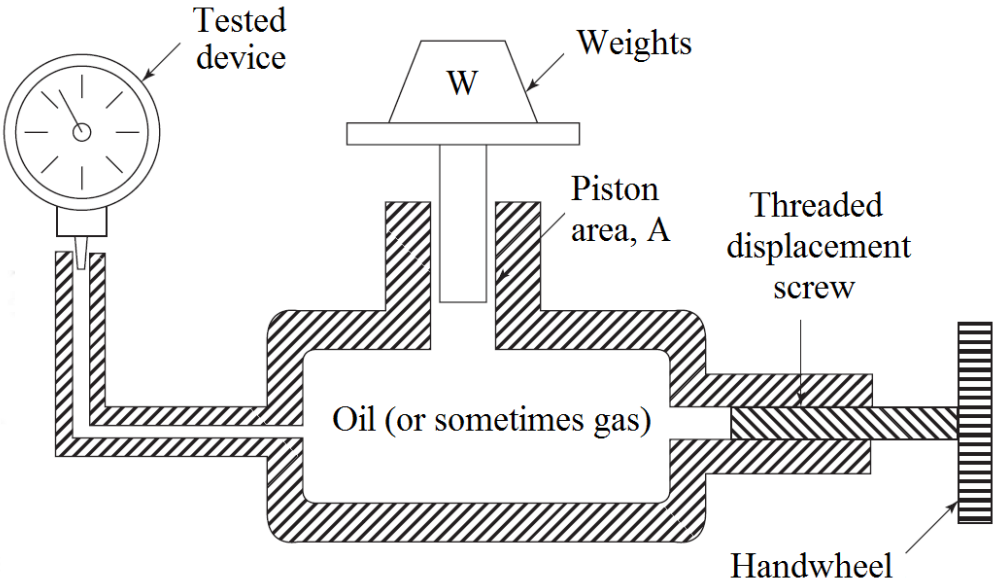
Pressure measurement

Mercury barometer



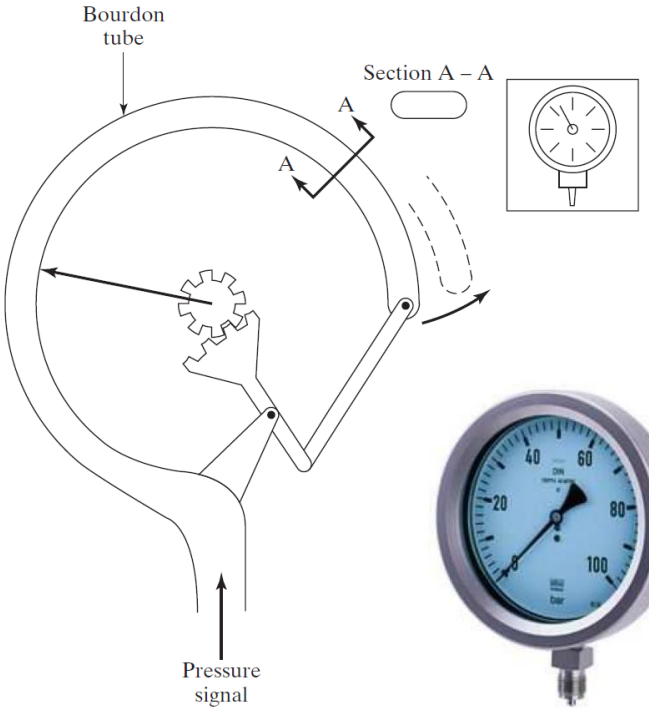
Pressure measurement

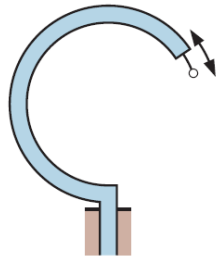
Dead-weight tester – mostly used for calibration of other manometers

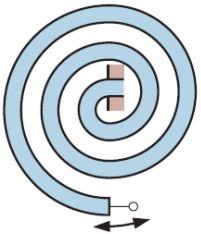


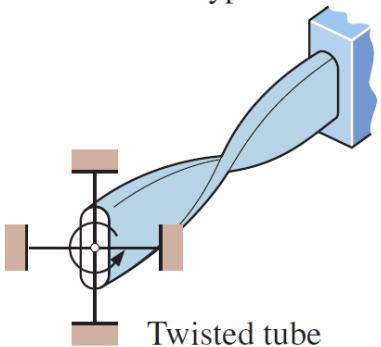
Pressure measurement

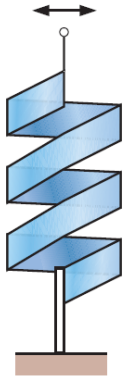
Bourdon gage

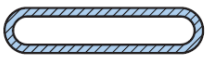










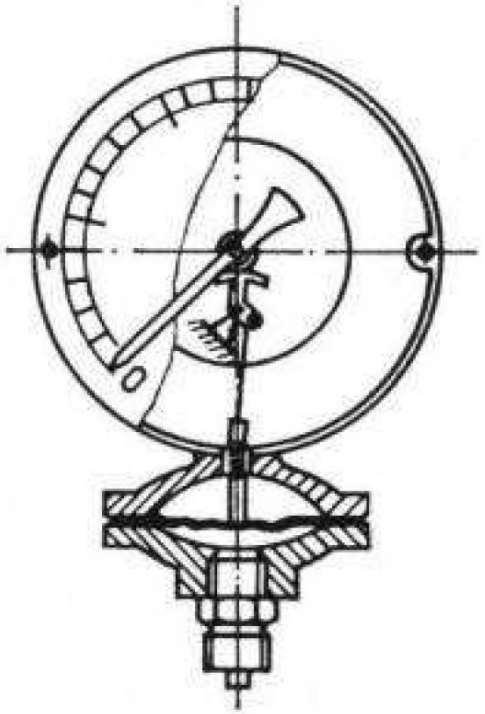


Pressure measurement

Bourdon gage – a principle similar to the party noise-maker

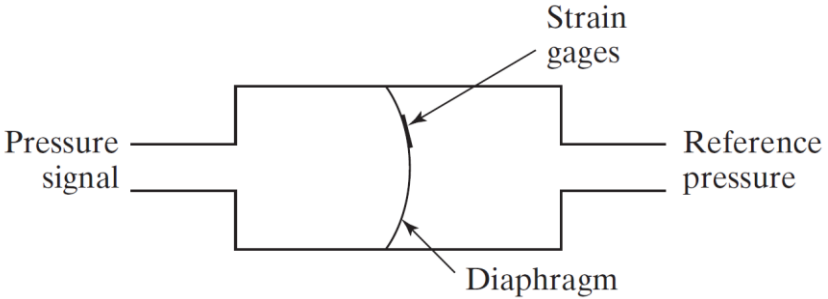
Pressure measurement

Diaphragm pressure gage

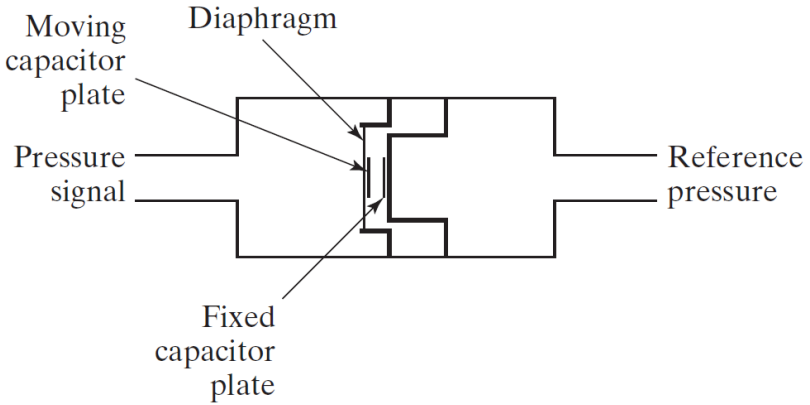


Pressure measurement

Strain-gage pressure transducer

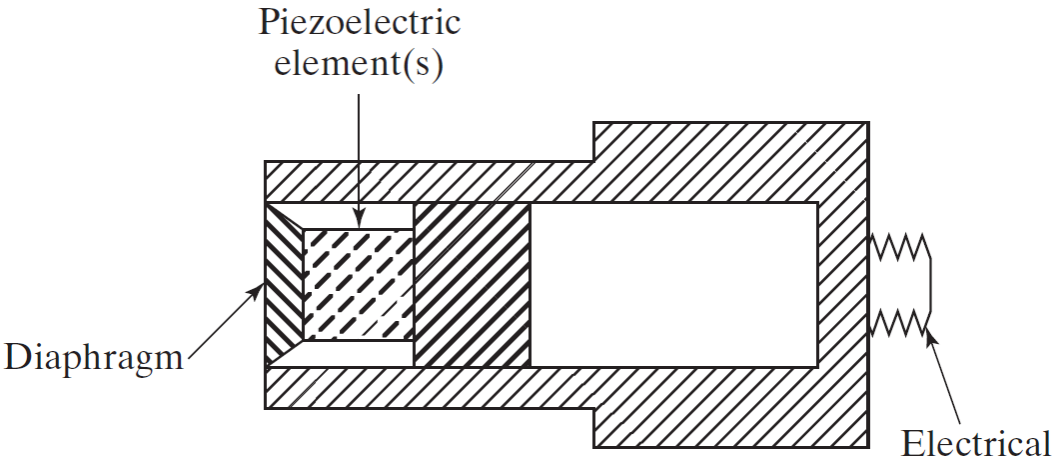


Capacitive pressure transducer



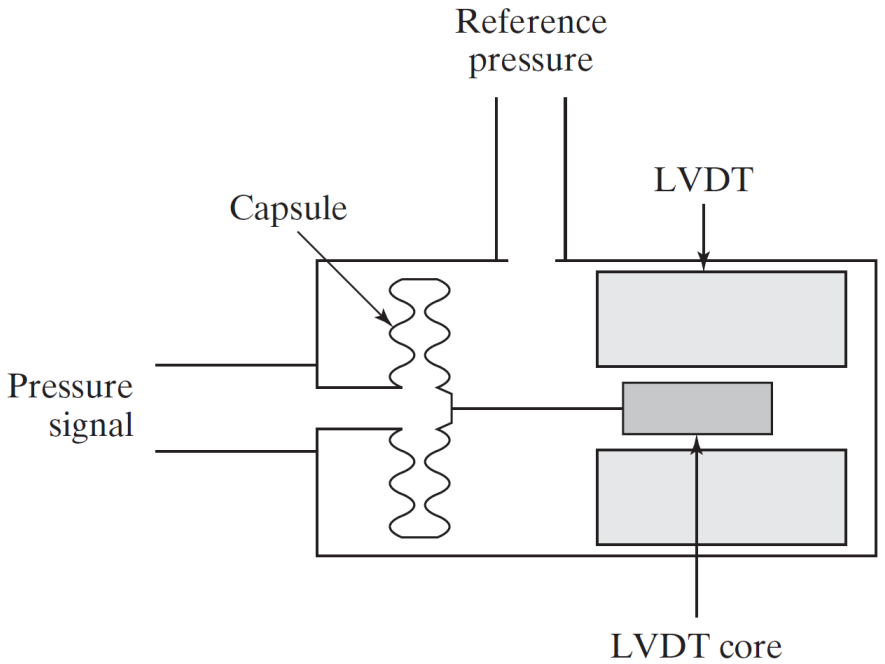
Pressure measurement

Piezoelectric pressure transducer



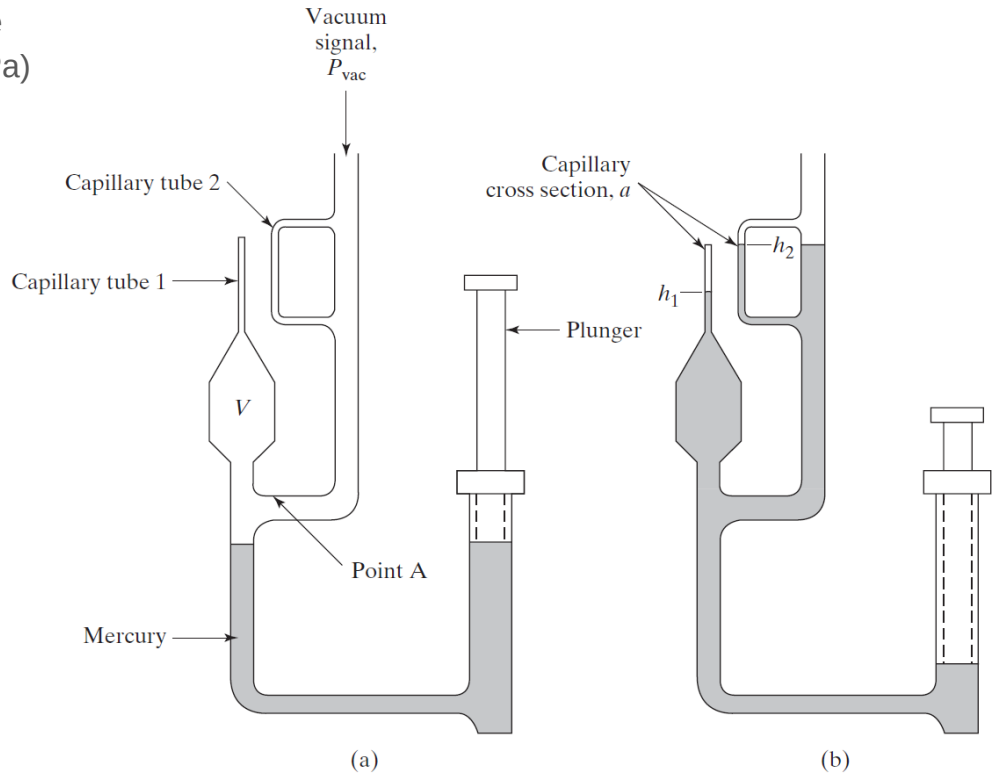
Pressure measurement

LVDT pressure transducer (Linear Variable Differential Transformer)



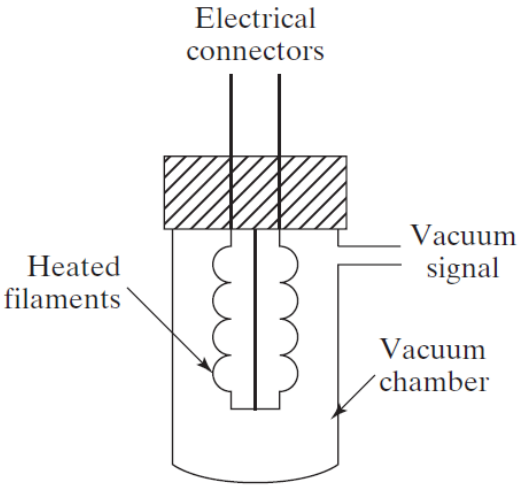
Very low pressure (vacuum) measurement

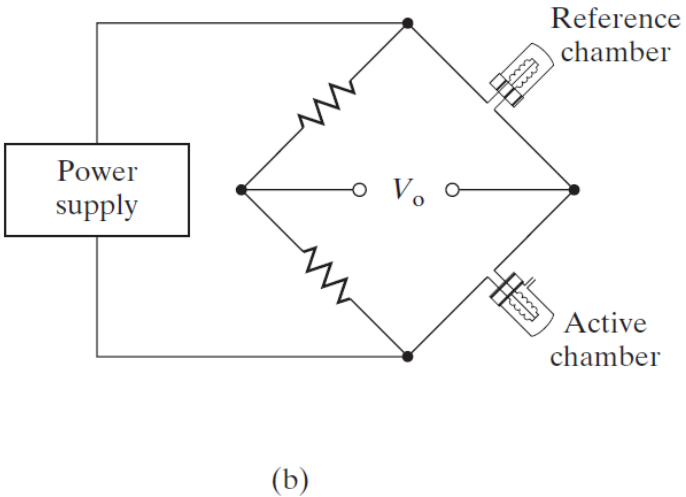
McLeod vacuum gage
(range of 10^3 to 10^{-4} Pa)



Very low pressure (vacuum) measureme

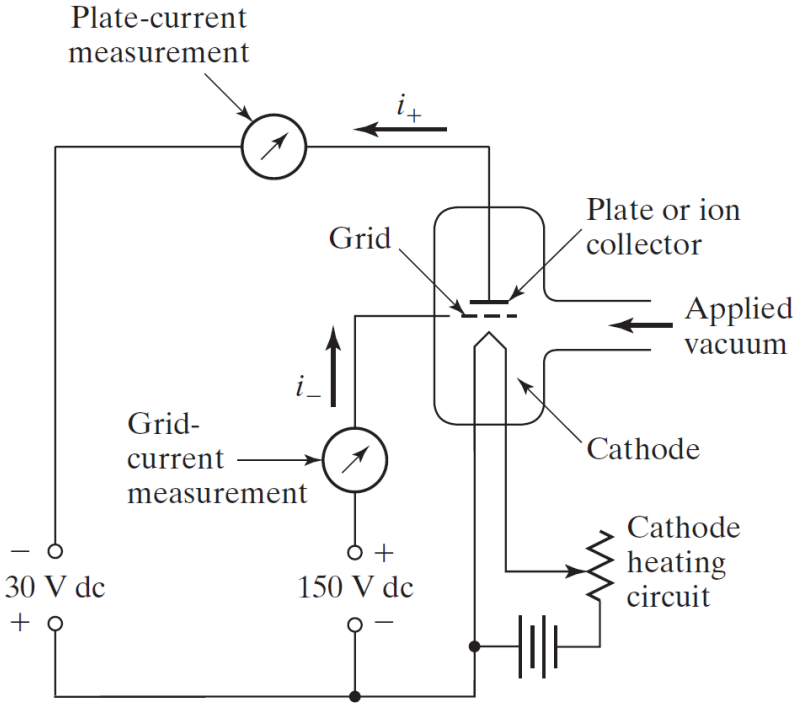
Pirani thermal-conductivity vacuum gage
(range of 10^3 to 10^{-3} Pa)





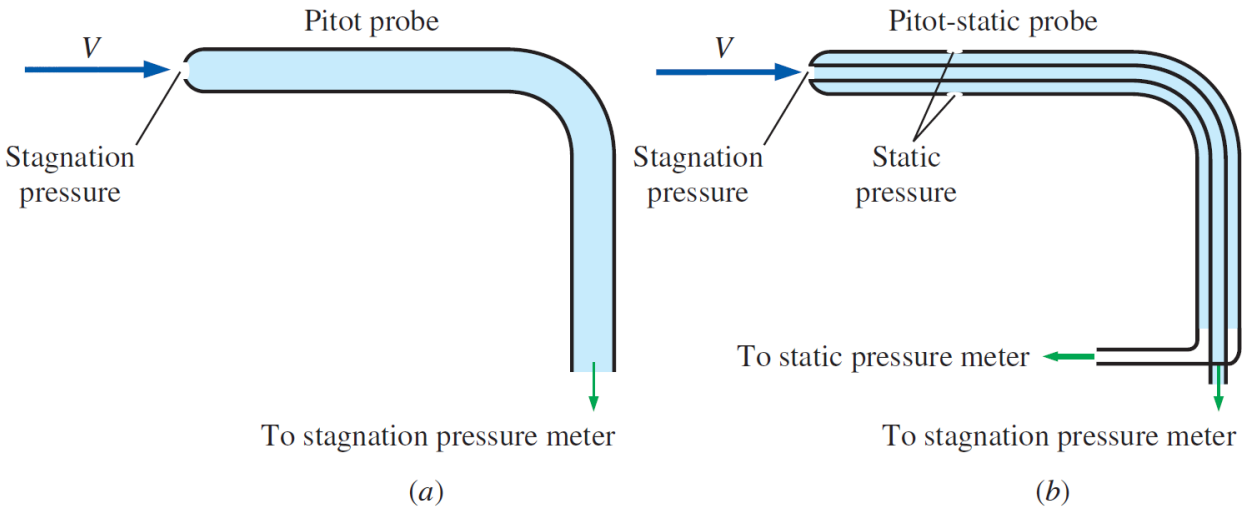
Very low pressure (vacuum) measurement

Ionization Vacuum Gage
(range of 10^{-1} to10^{-10} Pa)



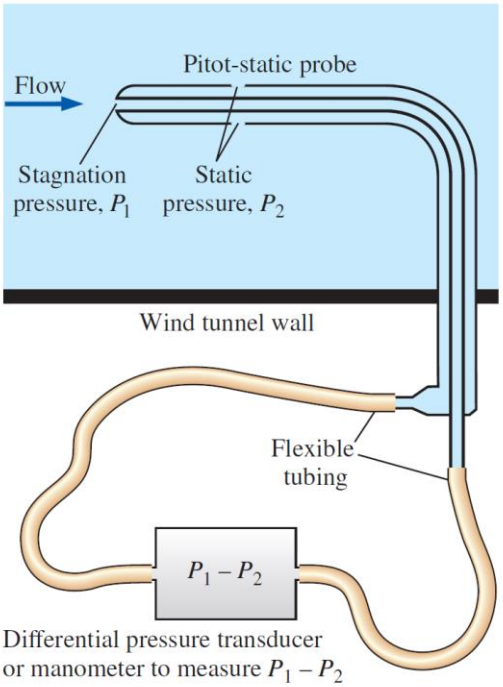
Measurement of **velocity** and flow rate

Pitot and Pitot-Static probe



Measurement of **velocity** and flow rate

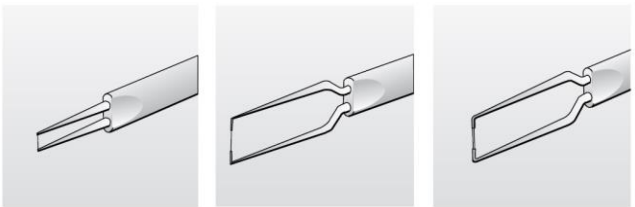
Pitot-Static probe

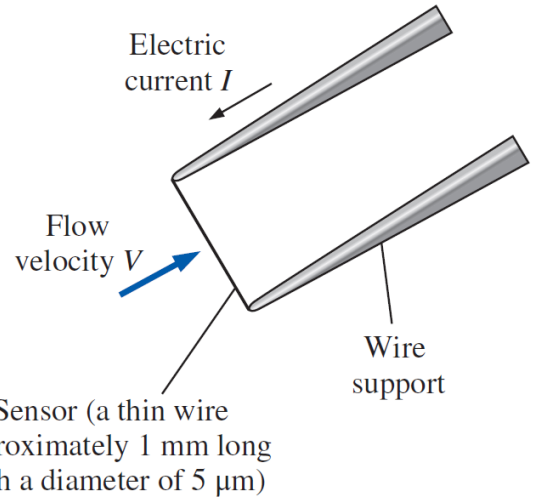


Measurement of **velocity** and flow rate

Thermal (Hot-Wire and Hot-Film) Anemometers – 2 possible working modes (CTA/CCA)

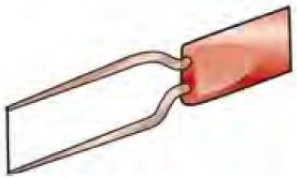
- **CTA** (Constant Temperature Anemometry) **for velocity measurement**
- **CCA** (Constant Current Anemometry) **for temperature measurement**



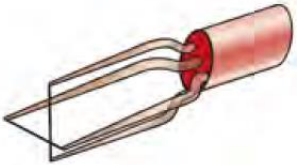


Measurement of **velocity** and flow rate

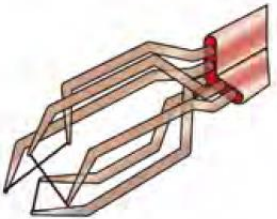
Thermal (Hot-Wire and Hot-Film) Anemometers – CTA/CCA



1D



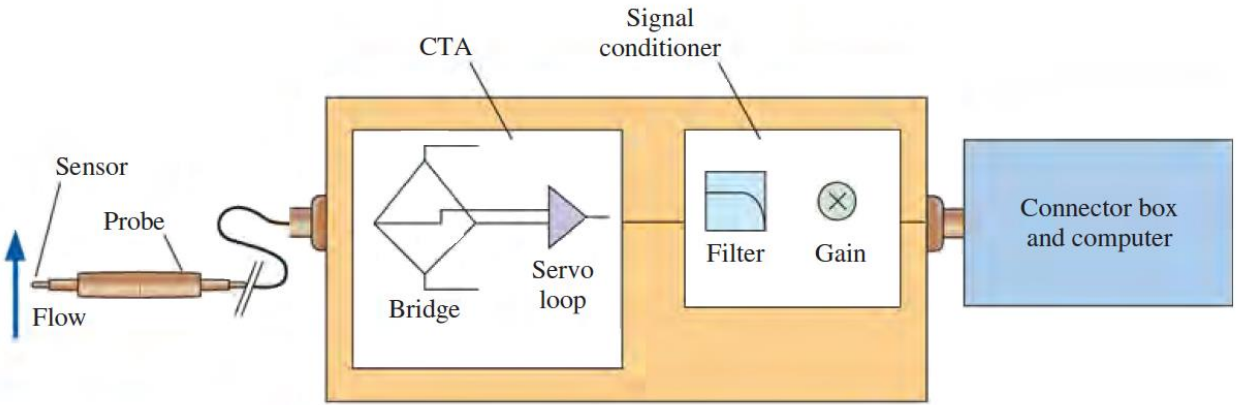
2D



3D

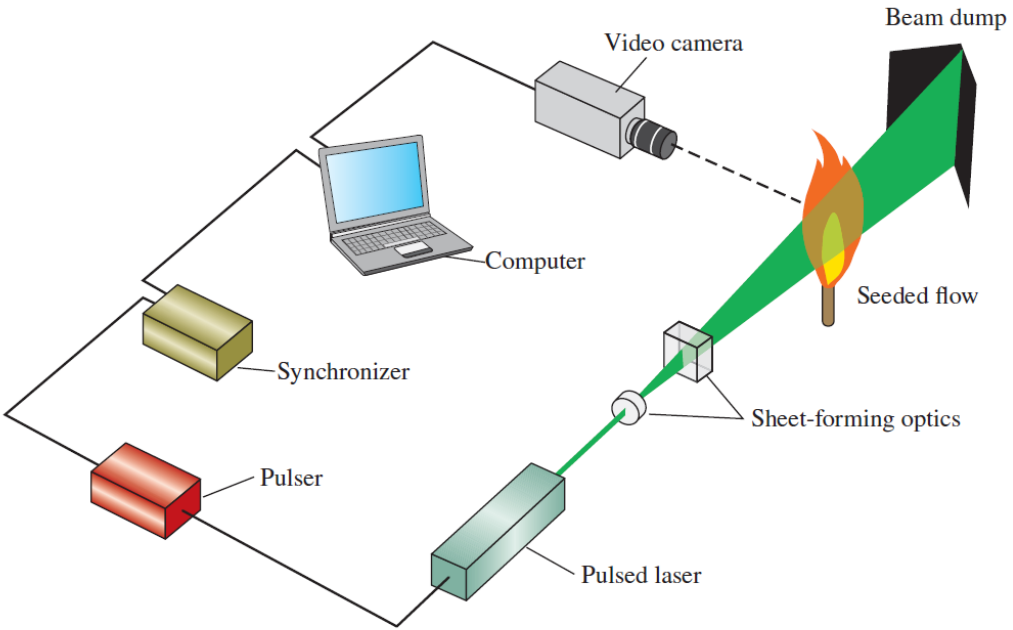
Measurement of **velocity** and flow rate

Thermal (Hot-Wire and Hot-Film) Anemometers – CTA/CCA



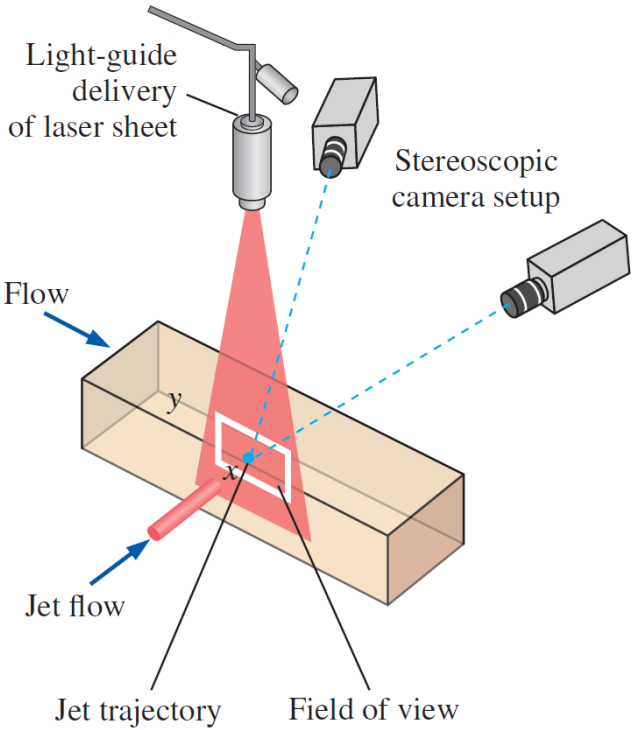
Measurement of **velocity** and flow rate

PIV (Particle Image Velocimetry) – a planar method



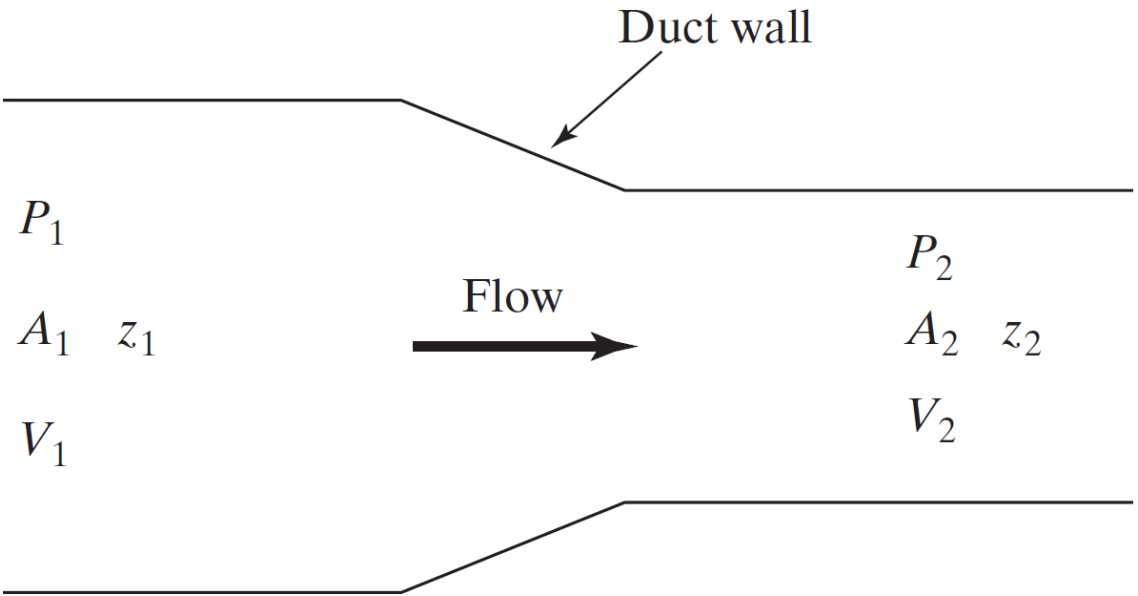
Measurement of **velocity** and flow rate

Stereo PIV (Particle Image Velocimetry)



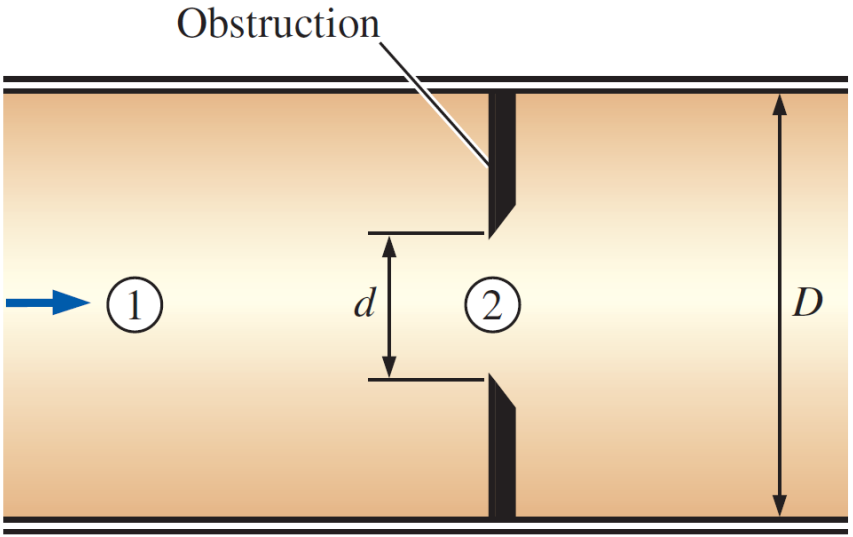
Measurement of velocity and **flow rate**

Obstruction Flowmeters: Orifice, Venturi and Nozzle Meters (ISO 5167)



Measurement of velocity and **flow rate**

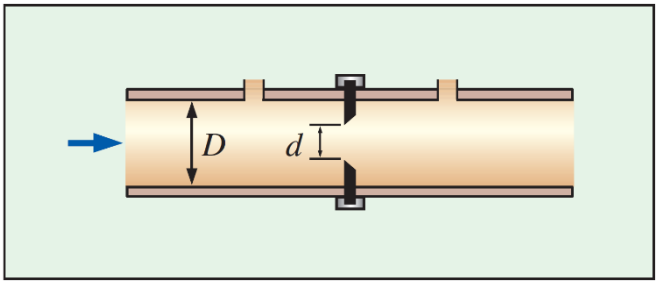
Obstruction Flowmeters: Orifice, Venturi and Nozzle Meters (ISO 5167)

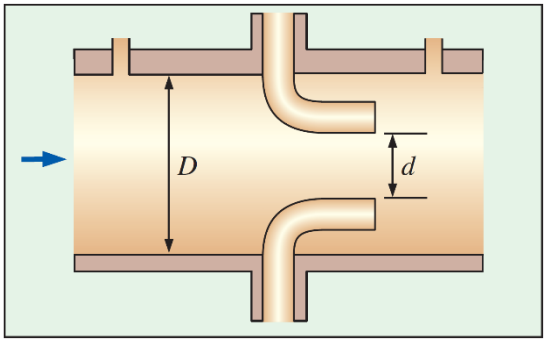


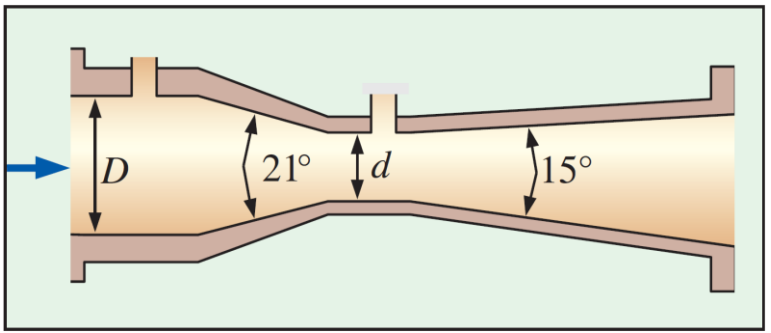
It is necessary to performe calibration and eventually make corrections for actual flow rate. It is also used for mass flow rate measurements (compressibility factor).

Measurement of velocity and **flow rate**

Obstruction Flowmeters: Orifice, Venturi and Nozzle Meters (ISO 5167-1 to 4)

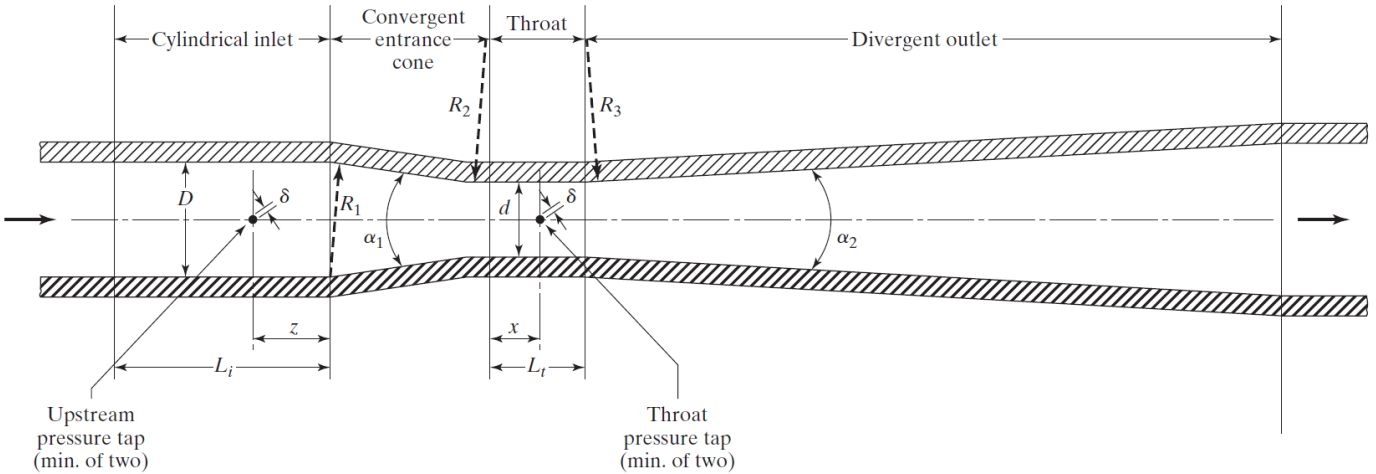






Measurement of velocity and **flow rate**

Obstruction Flowmeters: Venturi tube (ISO 5167-4)



$L_i > D$ or $L_i > (D/4 + 250$ mm (10 in.))
$z = D/2$ (+0.0 D, − $D/4$), minimum of 2 taps
$L_t \geq d/3$
$x = 0.5\,d \pm 0.02\,d$, minimum of two taps
4 mm (5/32 in.) $\leq \delta \leq$ 10 mm (25/64 in.) and $\delta < 0.1D$ or $0.13\,d$

$R_1 = 1.375\,D \pm 20\%$
$R_2 = 3.625\,d \pm 0.125\,d$
$5d \leq R_3 \leq 15\,d$
$\alpha_1 = 21° \pm 1°$
$7° \leq \alpha_2 \leq 15°$

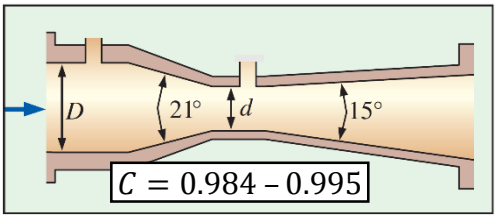
Measurement of velocity and **flow rate**

Obstruction Flowmeters: Venturi tube (ISO 5167-4)

TABLE 10.1 Discharge Coefficients for Venturi Tubes

Rough-Cast Entrance Cone and Rough-Welded Sheet-Metal Cone	Machined Entrance Cone
$C = 0.984 \pm 1.0\%$	$C = 0.995 \pm 1.0\%$
$4\text{ in.} \le D \le 48\text{ in.}$	$2\text{ in.} \le D \le 10\text{ in.}$
$0.3 \le \beta \le 0.75$	$0.3 \le \beta \le 0.75$
$2 \times 10^5 \le {}^{*}\text{Re} \le 2 \times 10^6$	$2 \times 10^5 \le \text{Re} \le 2 \times 10^6$

Source: ASME (1989).

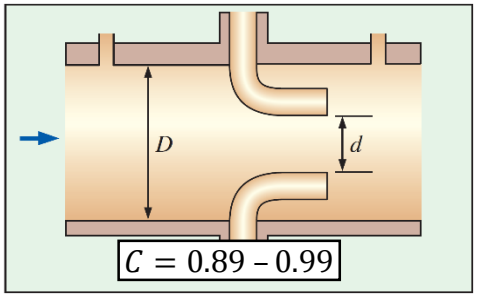


Measurement of velocity and **flow rate**

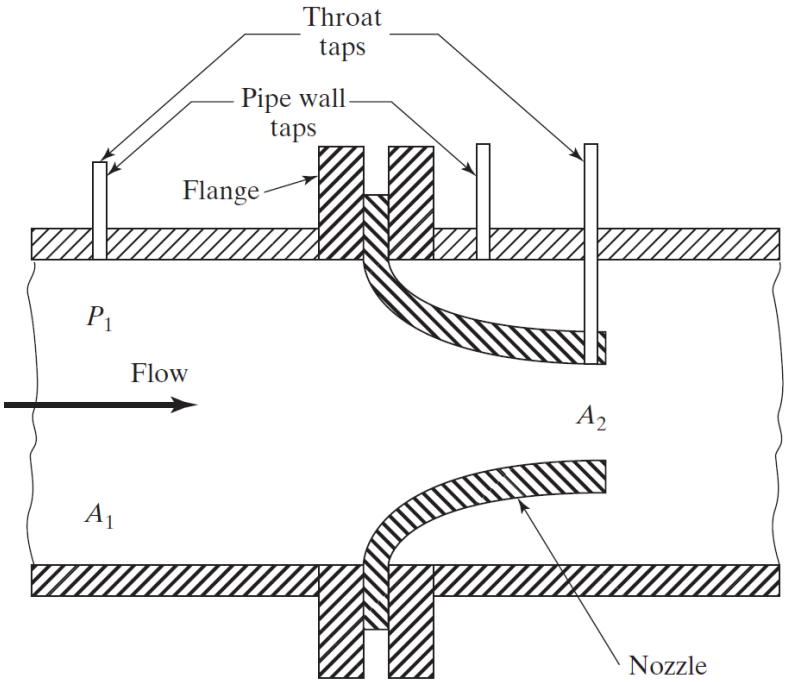
Obstruction Flowmeters: Venturi tube (ISO 5167-4)

Measurement of velocity and **flow rate**

Obstruction Flowmeters: Flow nozzle (ISO 5167-3), different designs

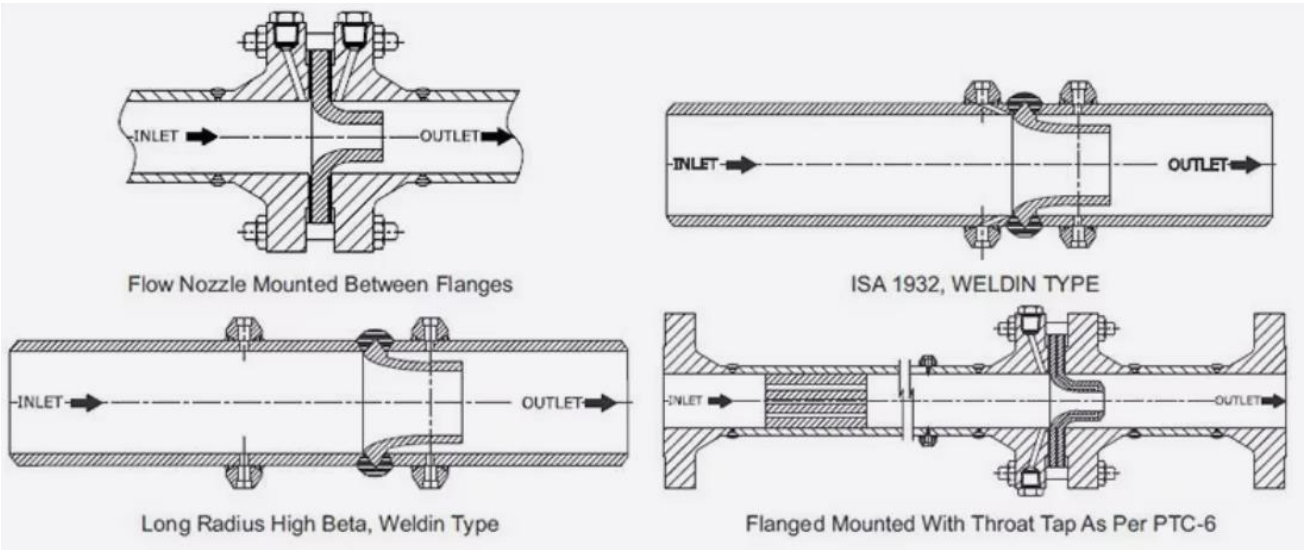


$$C = 0.9975 - 0.00653\sqrt{\left(\frac{10^6\beta}{Re_D}\right)}$$



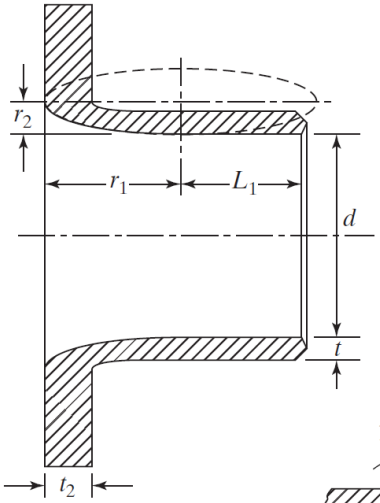
Measurement of velocity and **flow rate**

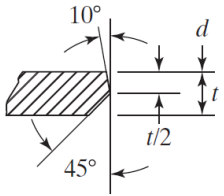
Obstruction Flowmeters: Flow nozzle (ISO 5167-3)



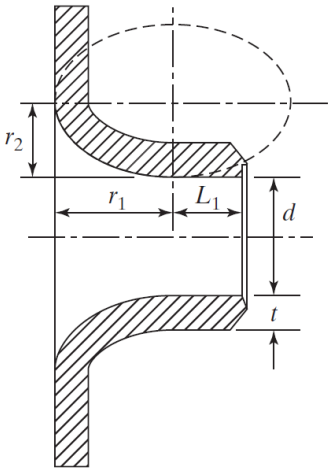
Measurement of velocity and **flow rate**

Obstruction Flowmeters: Flow nozzle (ISO 5167-3), e.g., the long-radius nozzle





Detail nozzle outlet



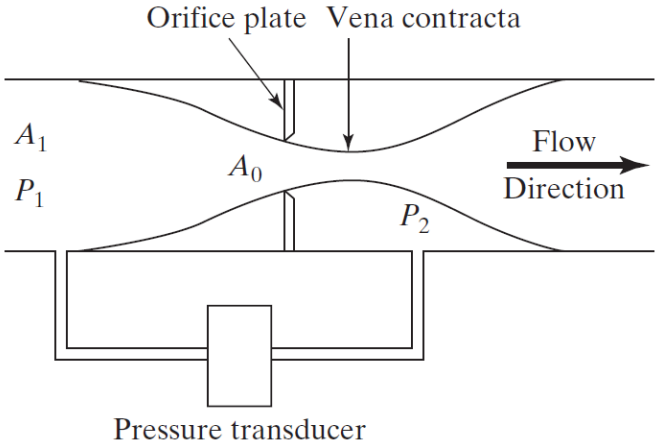
High β nozzle
$0.50 \le \beta \le 0.80$
$r_1 = D/2$
$r_2 = (D - d)/2$
$L_1 \le 0.6\,d$ or $\le D/3$
$2t \le D - (d + 6$ mm $[0.25$ in.$])$
3 mm [0.13 in.] $\le t_2 \le 0.15\,D$

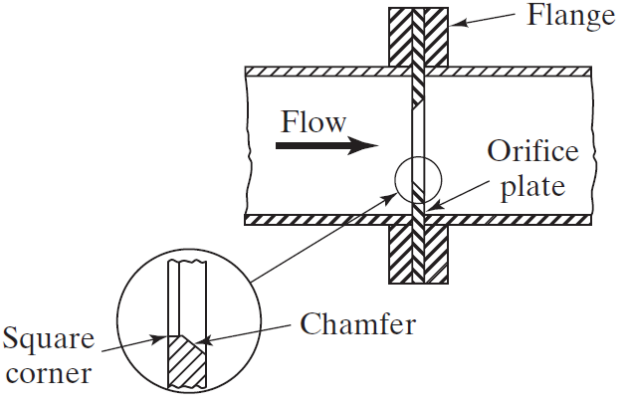
Low β nozzle
$0.20 \le \beta \le 0.50$
$r_1 = d$
$0.63\,d \le r_2 \le 0.67\,d$
$0.6\,d \le L_1 \le 0.75\,d$
3 mm [0.13 in.] $\le t \le$ 12 mm [0.5 in.]
3 mm [0.13 in.] $\le t_2 \le 0.15\,D$

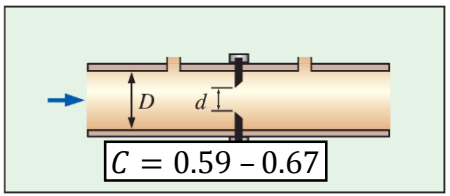
D = Upstream pipe inside diameter

Measurement of velocity and **flow rate**

Obstruction Flowmeters: Orifice plate (ISO 5167-2), different designs



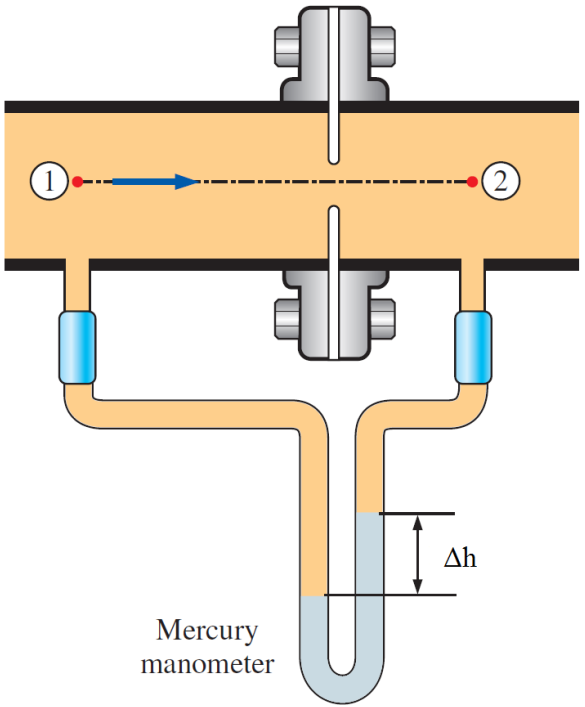




$$C = 0.5959 - 0.0312\beta^{2.1} - 0.184\beta^{8} + \frac{97.71\beta^{2.5}}{Re_D{}^{0.75}}$$

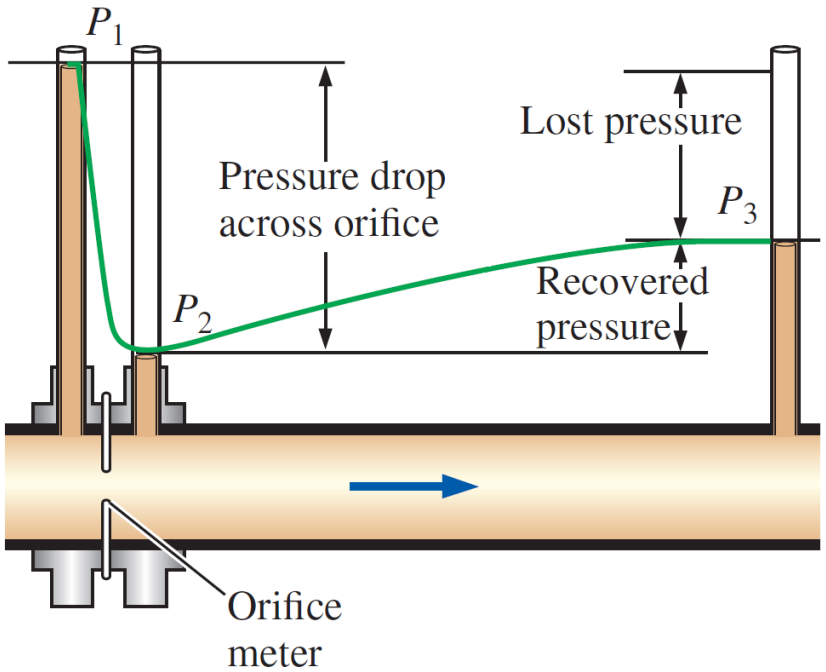
Measurement of velocity and **flow rate**

Obstruction Flowmeters – Orifice (ISO 5167-1(2))



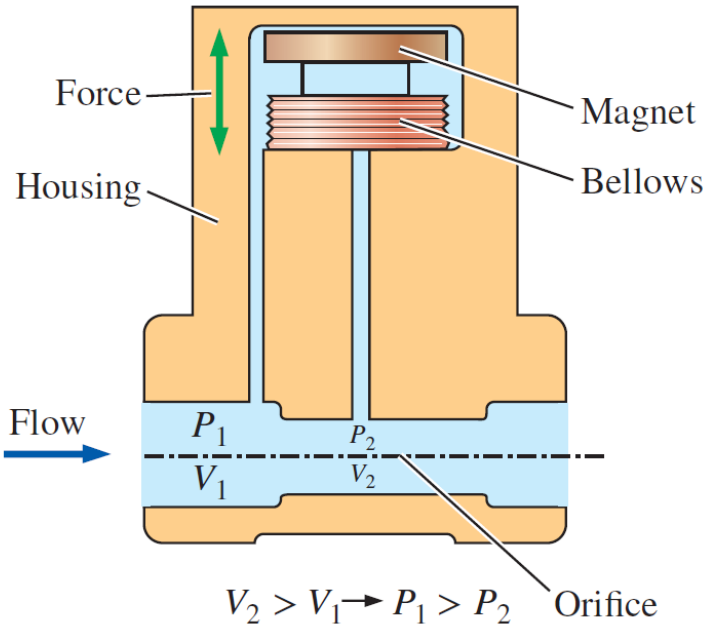
Measurement of velocity and **flow rate**

Obstruction Flowmeters – Orifice (ISO 5167-1(2)) – Pressure drop vs pressure loss



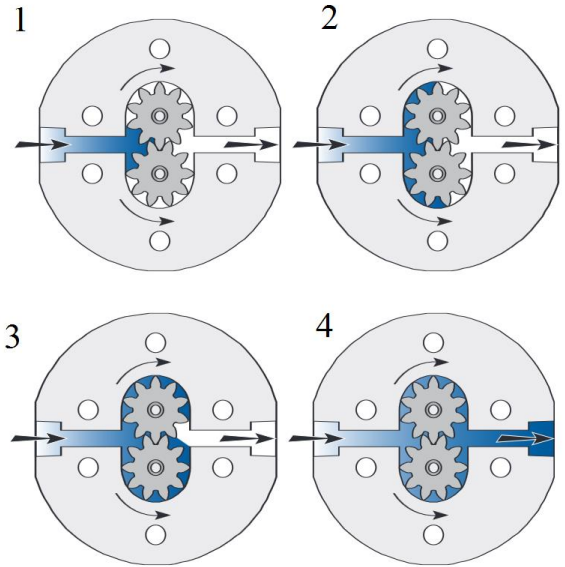
Measurement of velocity and **flow rate**

Obstruction Flowmeters: A practical example



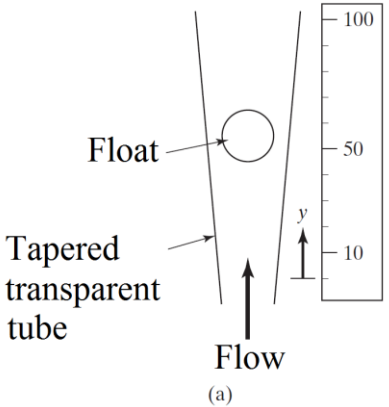
Measurement of velocity and **flow rate**

Positive Displacement Flowmeters

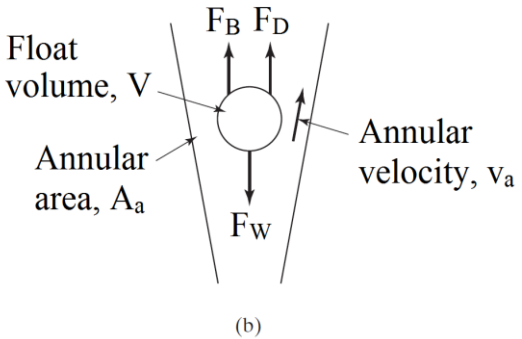


Measurement of velocity and **flow rate**

Variable-Area Flowmeters (Rotameters)



(a)



(b)

(*a*)

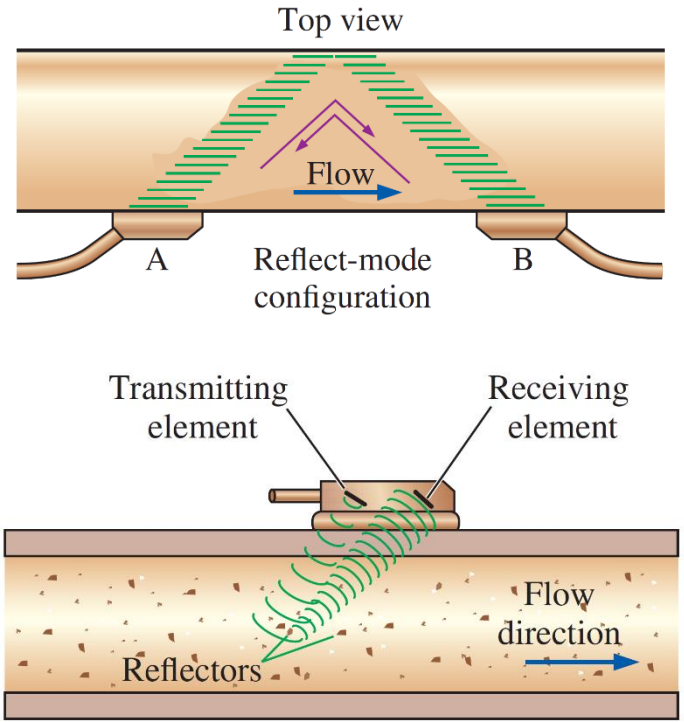

(*b*)

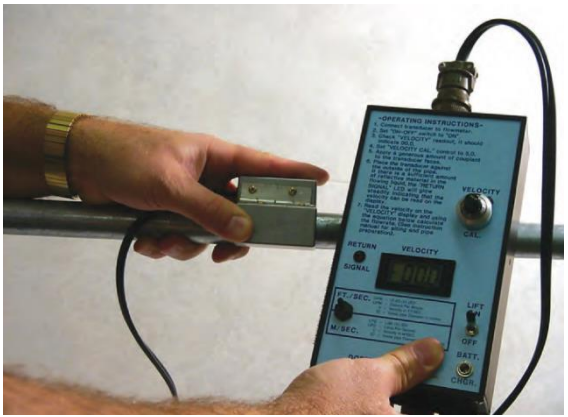
Measurement of velocity and **flow rate**

Turbine flowmeters (propeller flowmeters)

Measurement of velocity and **flow rate**

Ultrasonic flowmeters





Thank you!