7. Respiration

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Wright respirometer

Rotameter

Dräger volumeter

Fleisch Pneumotachograph

Poiseuille's Law

\[ \tau = \frac{8\eta L}{\pi r^4} \]

Avoid water condensation

Heater
**Turbulent Flowmeter**

This geometry produces turbulent flow, and causes a pressure drop proportional to the square of the flow rate between the upstream and downstream tubes.

\[ \Delta P \propto Q^2 \]

**Venturi Tube**

Bernoulli's theorem

\[ \frac{1}{2} \rho U^2 + P = \text{const} \]

The pressure difference is proportional to the square of the flow velocity.

**Hot-wire Anemometer**

The gas flow velocity is estimated by the amount of heat transfer from the wire to the gas, and the temperature difference between the wire and gas temperatures.

\[ H = \alpha \pi dl(T_w - T_g) \]

\[ \alpha = N_u k / d \]

\[ H = (a + b \sqrt{U})(T_w - T_g) \]

Heat dissipation: \[ H = RI^2 \]

**Servo-control Circuits for Hot-wire Anemometer**

The gas flow velocity is estimated by the amount of heat transfer from the wire to the gas, and the temperature difference between the wire and gas temperatures.

Nusselt Number

\[ N_u = \left( \frac{T_w - T_g}{2T} \right)^{0.17} \left( A + BU^n \right) \]
**Bidirectional Hot-wire Anemometer**

- Platinum wire (flow velocity)
- Tungsten wires (flow direction)

**Time-of-flight Flowmeter**

Flow velocity is measured by introducing a tracer into the upstream and detecting it in the downstream. When the separation between the introducing and detecting sites is known, flow velocity can be determined by the time-of-flight of the tracer. The most convenient tracer is a heated gas bolus.

**Time Course of Time-of-flight Flowmeter**

A short pulse current is applied to the wire.

- Pulsed wire temperature elevates then decreases due to the heat dissipation from the wire to the gas.
- Gas temperature at the sensor wire increases due to the heated gas bolus hitting the sensor wire.
- The heated gas bolus moves downstream and reaches the sensor wire.

**Pulsed-wire Time-of-flight Gas Flowmeter**

Detecting ambient temperature fluctuation.

-Mosse and Roberts 1987
Sing-around Method

A signal detected by the detecting (sensor) wire triggers the next pulse applied to the heating (pulsed) wire. The frequency output is proportional to the flow velocity.

Time-of-flight Flowmeter Using Sing-around Method

The diagram shows the flowmeter setup with input switch, controller, trigger, transmitter, receiver, and output switch. Switching the transducers and measuring the transit-time difference for N sing-around loops up and down stream measures the total time it takes to complete the N sing-around loops.

Ultrasonic Flowmeter

Transit time of downstream sound wave:
\[ t_1 = \frac{D}{c + U \cos \theta} \]

Transit time of upstream sound wave:
\[ t_2 = \frac{D}{c - U \cos \theta} \]

\[ U = \frac{c^2 \Delta t}{2D \cos \theta} = \frac{c^2 \Delta \phi}{2\omega D \cos \theta} \]

- **U**: flow velocity
- **c**: sound velocity
- **D**: distance between two crystals
- **\( \theta \)**: beam angle with respect to the flow
- **\( \Delta \phi \)**: phase difference

Diagonal Beam Ultrasonic Flowmeter Head

The flowmeter head diagram shows the ultrasonic transceiver, cross section, ultrasonic transducers, short tube termination, and thermocouple assembly. Short ultrasonic pulse trains are transmitted downstream and upstream simultaneously at 500 Hz.
Cylindrical Shell Ultrasonic Flowmeter Head

- Metal plating shield (grounded)
- Rubber rails
- Cylindrical shell crystal
- End cap
- Connector cable

Kármán Vortex Flowmeter

- Flow
- Rod
- Vortices
- Kármán vortex street generated behind a rod in the stream
- \[ f = \frac{S_U}{d} \]
- \( U \): flow velocity
- \( d \): diameter of the vortex generator
- \( S_U \): Strouhal number, a dimensionless number describing oscillating flow mechanisms

Swirlmeter

- Swirl flow
- Thermal sensor
- Swirl producing component
- Deswirl component
- Sensor
- Meter body

When the gas passes through the blades, it spins forming vortices. The vortices are detected by a thermal sensor, and the gas flow rate is determined by the number of vortices passing at the sensor in a unit time interval.

Spirometry

- Objective
  - To assess ventilatory function of the lung
- To assess ventilatory capacity:
  - Forced Vital Capacity (FVC)
  - Maximum Voluntary Ventilation (MVV)
- To assess airway obstruction:
  - Forced Expiratory Volume in the 1st second (FEV1)
  - Forced Expiratory Flow from 25% to 75% of vital capacity (FEF25-75%)
  - Peak Expiratory Flow Rate (PEFR)
Benedict-Roth Spirometer

the elevation of the bell is proportional to the expired air into the bell.

Bell Displacement Measurement

the displacement of the bell or bellows is detected electronically.

Bellows for Dry Spirometer

various bellows are used instead of water seals light-weight portable instruments

Spirometers

SpireTech S/80 CareFusion Corp.

SuperSpiro Micro Medical Ltd.
**Hand Held Spirometer**

- **Spirobank**
  - FutureMed America Inc.

- **IQspiro Digital Spirometer**
  - Midmark Corp.

**Body Plethysmographies**

For a confined gas held at a constant temperature, $pV = \text{constant} \rightarrow \text{Boyle's law}$

- The lung volume change is measured by the volume change of the body

**Body Plethysmograph**

- **Elite Body Plethysmography System**
  - Medical Graphics Corp.

**Inductance Plethysmography**

- Measures the changes in thoracic and abdominal cross-sectional area.

Lung volume change: $\Delta V = K_1 \Delta R + K_2 \Delta A$

Abdominal coil: $\Delta A$
**Impedance Pneumography**

- Two-electrode system
- Four-electrode system

- 20-100kHz
- 25-500µA

**Sensitivity of Impedance Pneumography at Different Somatotype**

\[ \Delta Z / \Delta V = 453.23 W^{-1.084} \quad (\Omega/L) \]

\( W \): body weight (kg)

**Impedance Pneumogram and Spirometric Record**

- Maximum inspiratory level
- Maximum expiratory level

\( \Delta V \): respired volume change

\( \Delta Z \): transthoracic impedance change

**Oxygen-uptake in Exercise**

*Essential function:*
- Ventilation
- Circulation
- Metabolism

*The maximum capacity of oxygen transport limits the maximum work load*

*Oxygen-uptake is the most important parameter*

Also known as VO\(_2\), ventilation of oxygen. A measure of how much oxygen your body is consuming at any given time. Unit: mL/min, L/min of oxygen consumed.
Portable Oxygen-uptake Measurement

A hood covers the head, a servo controlled blower draws outside air through the hood, adjusting its volume flow in order to keep the oxygen concentration in the hood constant. The flow rate of the blower is measured with a flowmeter, and oxygen concentration is measured by an oxygen meter.

Continuous Oxygen-uptake Measurement

A mask covers subject’s head, fresh air is drawn into the mask. A pump adjusts air flow $Q$ to keep the oxygen concentration in the mask constant.

Respiratory Monitoring

- Objective = detection of abnormal respirations
- Central sleep apnoea = brain's respiratory control centers malfunction
- Obstructive sleep apnoea = obstruction of the upper airway
- Small tidal volume (<500ml or 7ml/kg bodyweight)
- Low respiration rate (<12-20 bpm)

Airflow Sensors

- Oronasal sensors:
  - Temperature
  - Pressure
  - Hot-wire anemometer
  - Ultrasound
  - Moisture

Wearable during sleep
Disposable sensors available