Pressure Measurement

By Steve Mackay - Dean of Engineering

Engineering Institute of Technology

www.eit.edu.au

EIT ENGINEERING INSTITUTE OF TECHNOLOGY

EIT Micro-Course Series

- Every two weeks we present a 35 to 45 minute interactive course
- Practical, useful with Q & A throughout
- PID loop Tuning / Arc Flash Protection, Functional Safety, Troubleshooting conveyors presented so far
- Upcoming:
  - Electrical Troubleshooting and much much more…..
- Go to http://www.eit.edu.au/free-courses
- You get the recording and slides

www.eit.edu.au

EIT ENGINEERING INSTITUTE OF TECHNOLOGY

Topics

- Principles
- Pressure Sources
- Pressure Transducers - Mechanical
- Pressure Transducers - Electrical
- Installation
- Impact on overall loop
- Selection Tables
- The Future

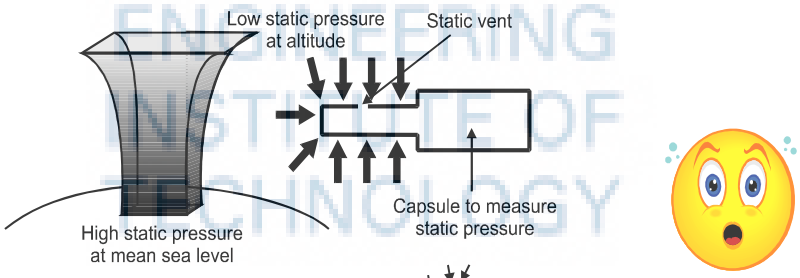
Principles

- Pressure = Force per unit area
- Units of psi, mm Hg and kPa
- Absolute Pressure referenced to a vacuum
- Gauge Pressure referred to one standard atmosphere
- Differential Pressure compares two different pressures

Pressure Sources

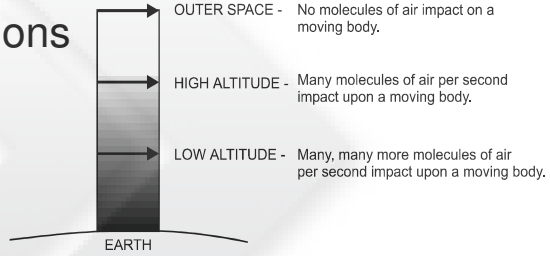
- Static Pressure
  - Due to weight of the molecules “pressing down”
- Dynamic Pressure
  - Relative movement when a body is moving through air

Static Pressure



Dynamic Pressure

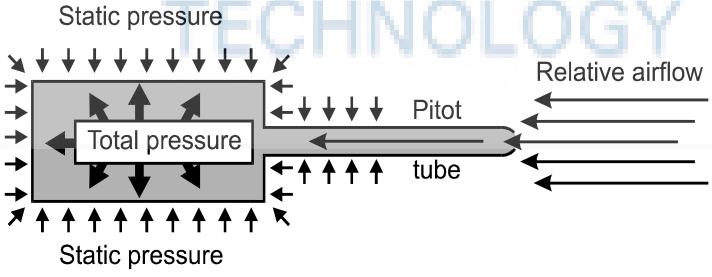
Pressure Variations



www.eit.edu.au

Total Pressure

- Total Pressure = Static Pressure + Dynamic Pressure



www.eit.edu.au

Pressure Transducers - Mechanical

- Bourdon Tube
- Helix and spiral tubes
- Spring and Bellows
- Diaphragm
- Manometer
- Single and Double Inverted Bell

www.eit.edu.au

C-Bourdon Tube

- Bent tube will change its shape when exposed to variations in internal or external pressure
- Orientation dependent for correct results
- Vertical mounting
- Wide Operating range

www.eit.edu.au

C-Bourdon

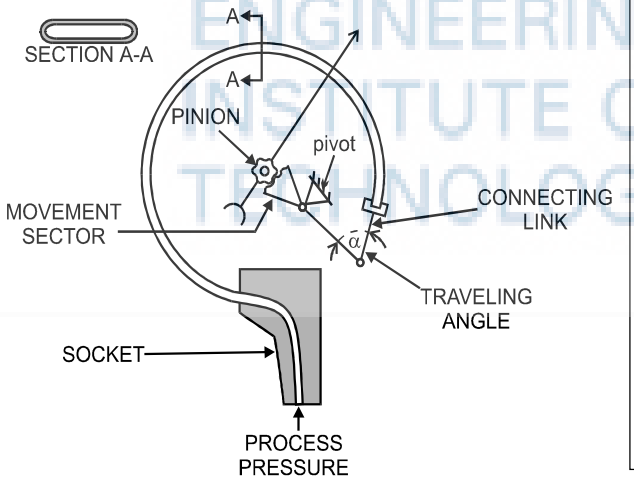
- Advantages
  - Inexpensive
  - Wide Operating Range
  - Fast response
  - Good sensitivity
  - Direct Pressure measurement

Disadvantages

- Primarily intended for indication only
- Non-linear transducer
- Hysteresis on cycling
- Sensitive to temperature variations
- Limited life when subject to shock and vibration

www.eit.edu.au

C-Bourdon Pressure Element



Limitations
•Use air if calibrated for air
•Use in liquid if calibrated for liquid
•Bleed air from the liquid lines
•Limited where there is input shock
•If for Oxygen, device cannot be calibrated for oil

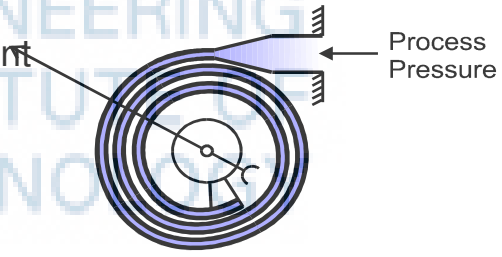
www.eit.edu.au

Helix and Spiral Tubes

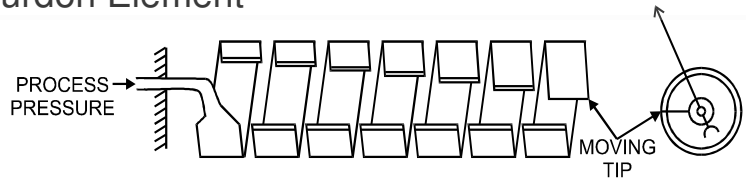
- With one end sealed, pressure causes the tube to straighten out
- Spiral suitable up to 28000 kPa
- Helical suitable up to 500000 kPa

Helix and Spiral Tubes

•Spiral Bourdon Element



•Helix Bourdon Element



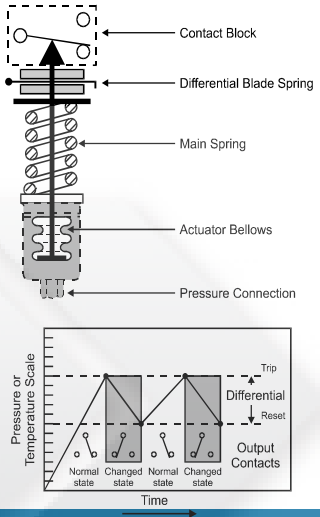
Spiral/Helix tubes

- Advantages
  - Increased accuracy and sensitivity
  - Higher overrange protection
- Disadvantages
  - Very Expensive

Spring and Bellows

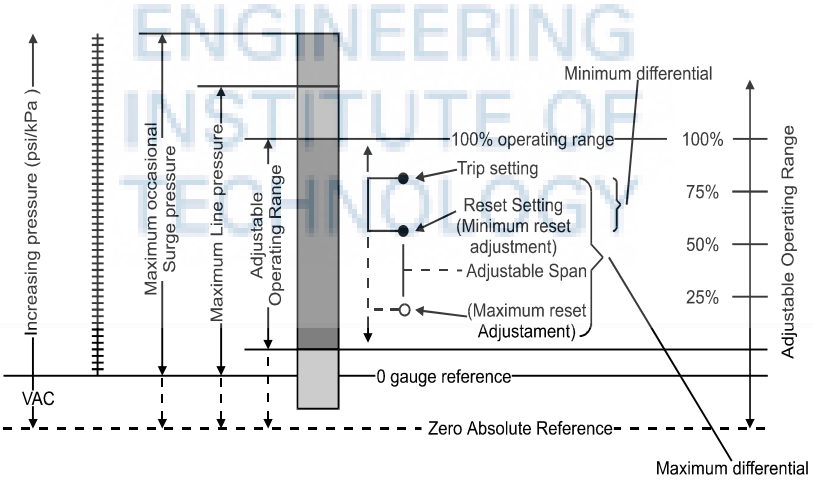
- Expandable element
- Free end responds to pressure
- Spring used to oppose force
- Linkage connects end to pointer for indication
- Primarily for ON / OFF control
- Provides clean contacts for electrical circuits
- Responds to pneumatic or hydraulic pressure changes

Spring and Bellows Switch



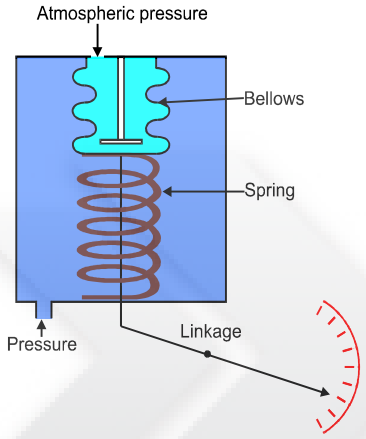
www.eit.edu.au

Technical Terms



www.eit.edu.au

Spring and Bellows Gauge



www.eit.edu.au

Diaphragm, Bellows or Piston?

- Pressure applied to actuator
  - Diaphragm, bellows or piston type
- Piston used for hydraulic fluids at high pressure
- Not used for air or water as accuracy is limited

www.eit.edu.au

Refrigeration Applications

- Pulsation generated by reciprocating refrigeration compressors
- Require additional pulsation dampening

Refrigeration Applications

Advantages

- Simple construction
- Easily maintained
- Inexpensive

Disadvantages

- Sensitive to temperature variations
- Work hardening of bellows
- Hysteresis
- Poor overrange protection

Application Limitations

- Range into vacuum required where settings approach 0 psi
- Surges of pressure can occur prior to steady state condition
- Bellows and fittings are specially prepared for oxygen and nitrous oxide

Diaphragm

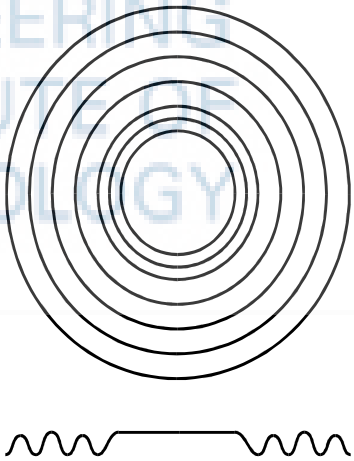
- Sensor measurement dependent on deflection of diaphragm
- Flexible disc
- Flat or with concentric corrugations
- Sheet metal with high tolerance dimensions

www.eit.edu.au

Simple Corrugated Diaphragm

Diaphragm Sensors

- Two main types :
  - Motion balanced
  - Force balanced



www.eit.edu.au

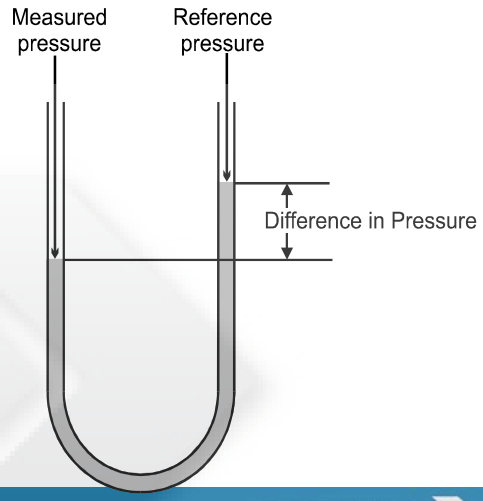
Advantages - Diaphragm

- Provide isolation from process fluid
- Good for low pressure
- Inexpensive
- Wide range
- Reliable and proven
- Used to measure gauge, atmospheric and differential pressure

Manometer

- Simplest form is U-shaped, liquid filled tube
- Reference and measured pressure applied to ends of tube
- Difference in pressure causes difference in liquid level between sides

Simplest Form of Manometer



Atmospheric Reference

- For water

1.0 Pa (Pascal) = 0.9807 mmH_2O

- For mercury

1.0 Pa (Pascal) = 133.3 mmHg

Typical Applications

- Mainly spot checks or calibration
  - Modern calibration using electronic meters
- Low range measurements
  - Higher measurements require mercury - toxic, therefore hazardous

Manometer

- **Advantages**
  - Simple operation and Construction
  - Inexpensive
- **Disadvantages**
  - Higher pressure range requires mercury
  - Range (water)
  - Readings are localised
- **Application Limitations**
  - Size limits operation to low range
  - Difficult to integrate into continuous control system

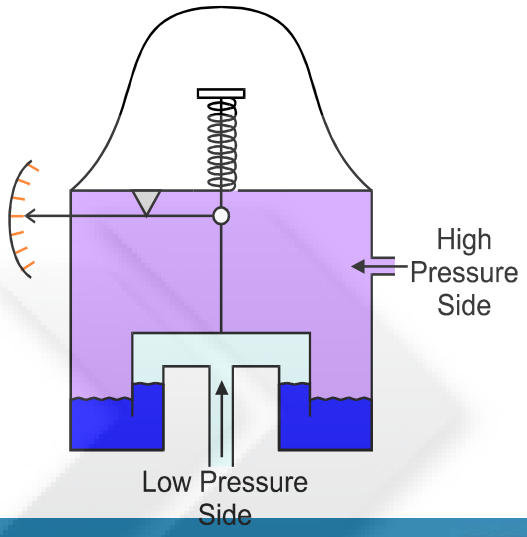
www.eit.edu.au

Single and Double Inverted Bell

- Measures pressure difference between sides of bell shaped compartment
- The bell instrument is used where very low pressures are to be measured, typically 0 - 250 Pa
- To reference to surrounding conditions
  - Gauge pressure measured
  - Lower compartment vented to outside

www.eit.edu.au

Inverted Bell d/p Detector



www.eit.edu.au

Pressure Transducers and Elements - Electrical

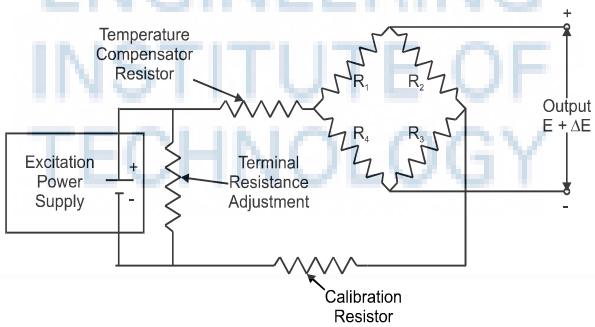
- Strain gauge
- Vibrating wire
- Piezoelectric
- Capacitance
- Linear Variable Differential Transformer
- Optical

www.eit.edu.au

Strain Gauges

- Metal wire or semiconductor chip
- Change in resistance as metal is deformed by pressure
- Temperature sensitive
  - Temperature compensation required
  - Often use Wheatstone bridge

Wheatstone Circuit for Strain Gauges



Typical Application

- Force
  - Applied to diaphragm
  - Through silicone fill fluid
  - To polysilicon sensor
- Reference side exposed to atmospheric pressure for gauge transmitters

www.eit.edu.au

Strain Gauges

Advantages

- Wide range, 7.5kPa to 1400MPa.
- Inaccuracy of 0.1%
- Small in size
- Stable devices with fast response
- Most have no moving parts
- Good overrange capability

Disadvantages

- Unstable due to bonding material
- Temperature sensitive
- Thermoelastic strain causes hysteresis

www.eit.edu.au

Vibrating Wire

- Electronic oscillator circuit causes natural frequency oscillation of wire
- Wire under tension in diaphragm
- Pressure changes causes changes in natural frequency

www.eit.edu.au

Vibrating Wire

Advantages

- Good accuracy and repeatability
- Stable
- Low hysteresis
- High resolution
- Absolute, gauge or differential measurement

Disadvantages

- Temperature sensitive
- Affected by shock and vibration
- Non-linear
- Physically large

www.eit.edu.au

Piezoelectric

- Crystals elastically deformed when force applied
- Measure rate of change of deformation
- Electrical output proportional to applied acceleration

Piezoelectric

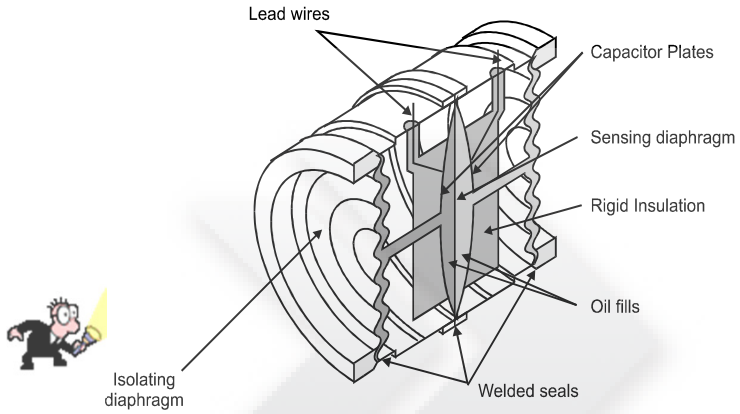
•Advantages

- Accuracy 0.075%
- Very high pressure measurement, up to 70MPa.
- Small size
- Robust
- Fast response, < 1 nanosecond
- Self-generated signal

•Disadvantages

- Dynamic sensing only
- Temperature sensitive

Cross Section of the Rosemount d-CellTM Sensor



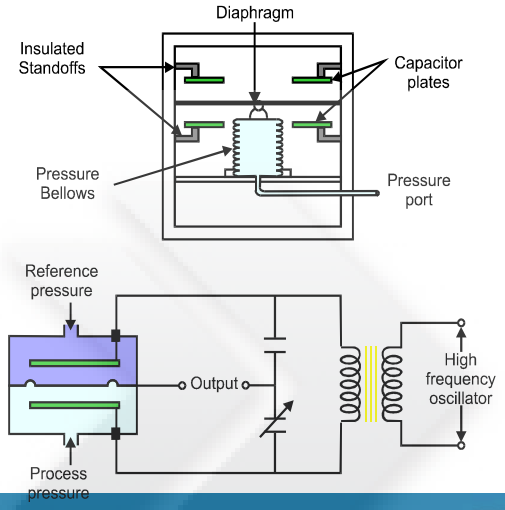
www.eit.edu.au

Capacitance

- Diaphragm movement causes capacitance change
- Sensor energised by a high frequency electrical oscillator
- Relative capacitance measured by bridge circuit

www.eit.edu.au

Capacitance Measurement



www.eit.edu.au

Capacitance

Advantages

- Inaccuracy 0.01 to 0.2%
- Range of 80Pa to 35MPa.
- Linearity
- Fast response

Disadvantages

- Temperature sensitive
- Stray capacitance problems
- Vibration
- Limited overpressure capability
- Cost

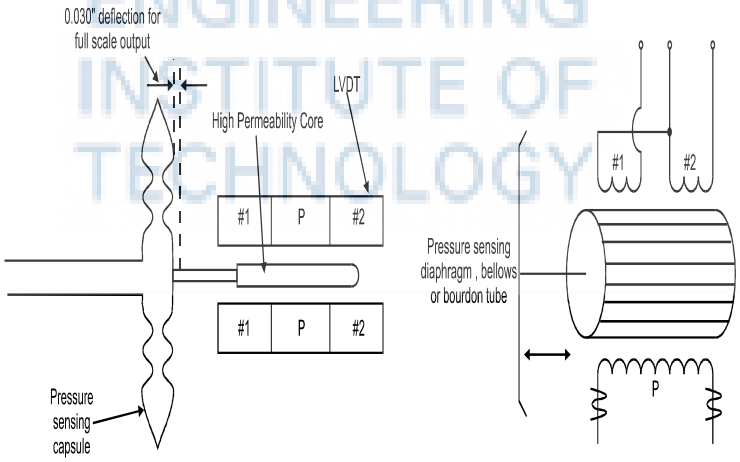
www.eit.edu.au

Linear Variable Differential Transformer

- Movement of high permeability material within transformer coils
- Pressure transferred via diaphragm, bellows or bourdon tube

Disadvantages →
- Mechanical wear
- Vibration

Linear Variable Differential Transformer

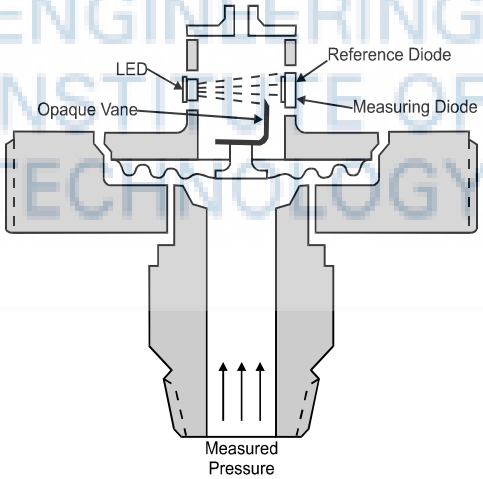


Optical

- Opaque vane mounted to the diaphragm
- Vane moves in front of infrared beam
- Received light indicates position of the diaphragm

www.eit.edu.au

Optical Pressure Sensor



www.eit.edu.au

Optical

Advantages
- Temperature corrected
- Good repeatability
- Negligible hysteresis

Disadvantages
- Expensive

www.eit.edu.au

Installation considerations

- Location of Connections
- Isolation Valves
- Impulse Tubing
- Test and Drain Valves
- Construction
- Temperature
- Remote Diaphragm Seals
- Precautions with Remote Diaphragm Seals
- Process Flanges
- Additional Hardware

www.eit.edu.au

Location of Process Connections

- Top of process line for gases
- Side of lines for other fluids

Isolation Valves

Between process fluid and measuring equipment if device is to be taken out

Use of Impulse tubing

Impulse piping

- Short as possible
- Self draining by sloping lines towards the process

Test and Drain Valves

- Blowdown valve needed for toxic or corrosive fluid

Sensor Construction

Mechanical and thermal isolation
- Away from process flange
- Position in neck of electronics housing

Temperature Effects
- Wheatstone bridge often used to compensate for temperature effects

Remote Diaphragm Seals

NEEDS
- Corrosion is possible
- Fluid viscosity may cause clogging
- Process temperature is outside normal operating temperature of transmitter
- Fluid may solidify
- Fluid needs to be flushed
- Maintaining sanitary or aseptic conditions
- Making density or other measurements.

Remote Diaphragm Seals

Precautions

- Large diameter minimises temperature effects
- Short capillary reduces temperature effects
- Transmitter below lower tap when using vacuum
- Fluid to cope with extremes, ie temp and pressure
- Fill and process fluids compatible
- In two seal system use same
  - fluid
  - diaphragm diameter
  - capillary length

www.eit.edu.au

Process Flanges

- Coplanar flange
  - Becoming more standard
- Level flange
  - Permits direct process mounting
- Traditional flange
  - Traditional biplanar configurations

www.eit.edu.au

Additional Hardware

- If pulsation dampeners are required the material and fill fluids must be compatible with the process fluid
- Siphons of correct material required for vapours above 60oC

Overall Control Loop

•Impact

Longer response due to material build-up on sensing element

Over-ranging causing incorrect readings

Thank You For Your Interest

If you are interested in further training, please visit:

IDC Technologies Short Courses:
Two-day practical courses available to the public:
http://idc-online.com

IDC Technologies Conferences:
http://idc-online.com/conferences-main

The Engineering Institute of Technologies
Online Certificate and
Advanced Diploma programs:
www.eit.edu.au

www.eit.edu.au