Thermo-Fluid Sensors:

Common thermos-fluid sensors include:

- Measuring pressure,
- Fluid flow rate,
- Temperature and
- Heat transfer rate.

measured / Ref. / density / accel. due to gravity / height of Column

$P - P_{ref} = \rho g h$

Gauge Pressure $P - P_{ref} = \rho g h$

Pressure Sensors:

$P = F/A$ ∴ Pressure Measured by measuring F using a force Sensor.

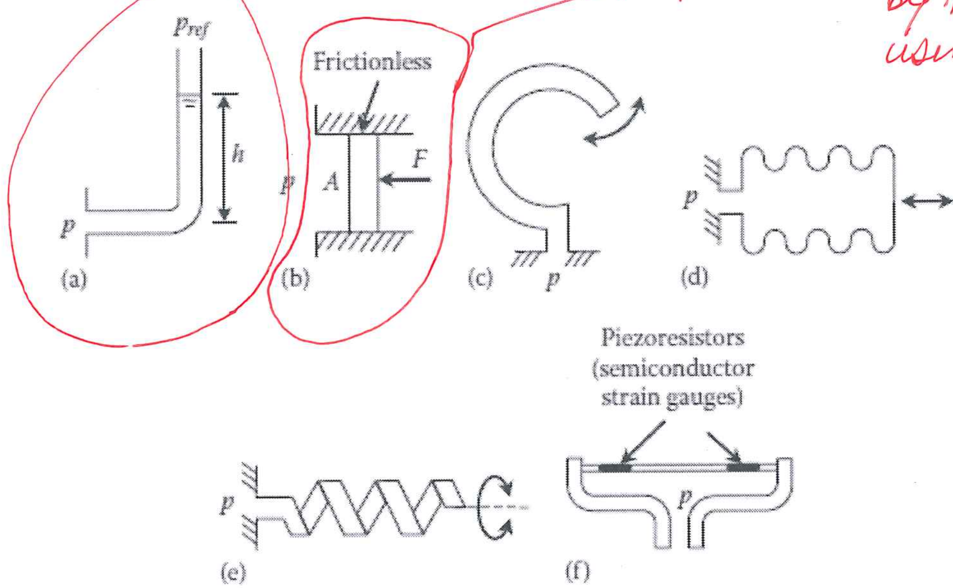


FIGURE 5.59 Typical pressure sensors. (a) Manometer, (b) counterbalance piston, (c) bourdon tube, (d) bellows, (e) helical tube, and (f) diaphragm.

c) Deflects the straightening motion as a result of internal pressure. Deflection can be measured by displacement sensor, Rotary, Moving pointer

d) Deflection due to "Internal Pressure", causing a linear motion - Using LVDT or CAP Sensor

e) Undergoes a Twisting Motion/Rotational Motion and Can be measured by RVDT, resolver, Potentiometer.

f) use piezoresistive strain-gauges to measure pressure.

Flow Sensors:

mass flow rate $\rightarrow Q_M = \rho Q$ — ρ: mass density, Q: Volume flow rate

Flow rate across an area 'A' @ av. vel. v : $Q = Av$

Bernulli's eqn of incompressible is given as $P + \frac{1}{2}\rho v^2 = $ Constant

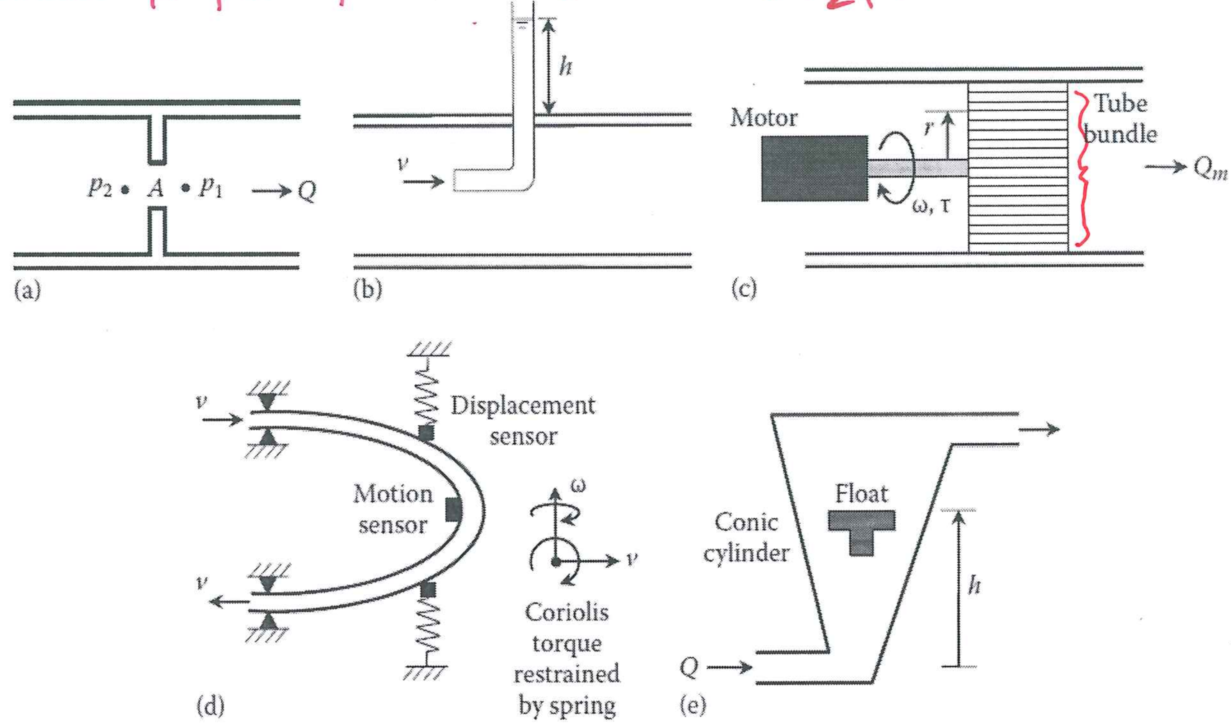


FIGURE 5.60 Several flowmeters. (a) Orifice flowmeter, (b) pitot tube, (c) angular-momentum flowmeter, (d) coriolis velocity meter, and (e) rotameter.

a) Flow across a constriction $Q = C_d A \sqrt{\frac{2\Delta P}{\rho}}$ — ΔP: Pressure drop across constriction; ρ: mass density; C_d: discharge Coeffs.

b) Noting that fluid velocity @ the free surface of the tube is zero $V = \sqrt{2gh}$ (Flow Vel)

c) Motor TORQUE $\tau = \omega r^2 Q_m$; ω: ANGULAR SPEED; Q_m: mass flow Rate; r: Centroid radius of Rotating fluid Mass.

d) Fluid is made to flow through U segment, which is hinged to oscillate out of plane @ ω (measured by Motion Sensor) and restrained by Springs (K) (measured by displacement Sensor)

e) Cylindrical object is floated in the conic tube, through which the fluid flows. Weight of object = pressure diff on object
- when flow speed ↑ object rises, ∴ More clearance for fluid to flow.

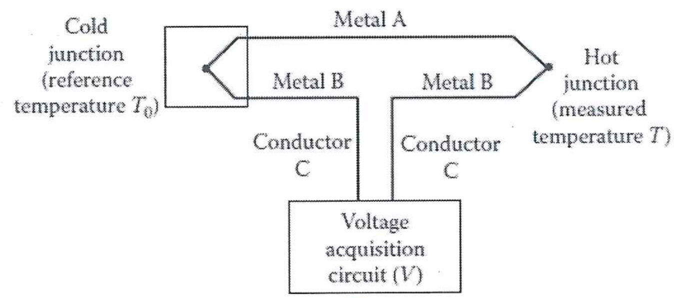
Level increase ⇒ flow rate

Temperature Sensors:

In most (if not all) temperature measuring devices, the temperature is sensed through heat transfer *from the source to the measuring device*. The physical (or chemical) change in the device that is caused by this heat transfer is the transducer stage of the sensing device.

Thermocouple:

When the temperature changes at the junction formed by joining two unlike conductors, its electron configuration changes due to the resulting heat transfer.



- This electron reconfiguration produces a voltage (emf), and is known as the ***Seebeck effect*** or ***thermoelectric effect***. Two junctions (or more) of a thermocouple are made with two unlike conductors such as iron and constantan, copper and constantan, chrome and alumel, and so on.
- One junction is placed in a reference source (cold junction) with temperature T_0 and the other in the temperature source (hot junction) of temperature T, as shown in Figure. The voltage V across the two junctions is measured to give the temperature of the hot junction with respect to the cold junction.
- The associated relationship (approximately) is:

Voltage V: $V = \alpha(T - T_0) + \gamma(T^2 - T_0^2)$

Temp Range
Speed
Sensitivity
Robustness to Vibration
ease of use

Resistance Temperature Detector (RTD):

A RTD is a *thermos-resistive* temperature sensor. It is a metal element (in a ceramic tube) whose resistance typically increases with temperature, according to a known function. A linear approximation is given by

$R = R_0(1 + \alpha T)$ ← Temp coeff of Resistance.

TABLE 5.10 Temperature Coefficients of Resistance of Some RTD Metals

Metal	Temperature Coefficient of Resistance α (°K)
Copper	0.0043
Nickel	0.0068
Platinum	0.0039

Thermister: $R = R_0 \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$ ← characteristic

BiMetal strip Thermometer
- Diff. Material Bend diff Motion Displacement → T Temp ~ 4200 K

Resonant Temp. Sensors. $T \propto$ Resonant f

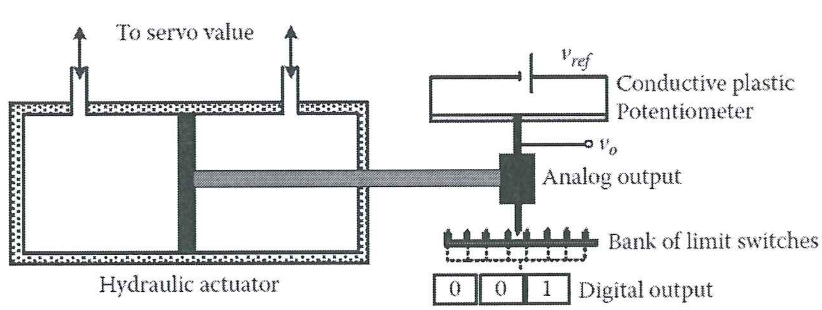
SiO_2 → Single Crystal Silicon Di-oxide → Very Accurate!!

Digital and Innovative Sensing:

So far we studied analog sensors and transducers. Let's look at digital transducers and some other innovative sensing methodologies. Our primary focus here is on transducers in mechatronic systems including motion sensors.

- Force, torque, temperature, and pressure, may be converted into a motion and subsequently measured using a motion transducer.
- Bimetallic element may be used to convert temperature into a displacement, which may be measured using a displacement sensor.
- It is acceptable to call an analog sensor as an analog transducer, because both the sensor stage and the transducer stage of it are analog.
- Typically, the *sensor stage of a digital transducer is typically analog* as well motion, since it is continuous in time and therefore, we cannot *generally speak of digital motion sensors*.
- It is the *transducer stage that generates a discrete output* signal (e.g., pulse train, count, frequency, encoded data) in a digital measuring device. Hence, digital sensing devices may be termed digital transducers rather than digital sensors.
- Other important sensor technologies that are microelectromechanical systems MEMS) sensors, multisensory data fusion, and wireless sensor networks (WSNs).

Analog versus Digital Sensing



Analog and digital methods for displacement sensing.

Analog Sensing Method Potentiometer with 3-bit ADC	Digital Sensing Method Eight Limit Switches
1. An ADC is required to acquire the data by a computer.	1. Easier to acquire data into a computer (e.g., the 1-bit output of a limit switch is typically TTL compatible and can be directly acquired by a microcontroller).
2. Data accuracy is lost in sampling (i.e., aliasing error), and cannot be recovered; signal/sensor noise directly enters into the reading.	2. The 3-bit accuracy is precisely retained even if the limit switch signal has high noise (because only a 1-bit information—triggered or not—is needed from a limit switch).
3. It can sense continuous signals with fine resolution. Resolution of the digitized signal can be improved by using an ADC of larger bit size (say, 4-bit).	3. The resolution is fixed by the number of limit switches.
4. Less robust due to reasons 2, 6, and 7.	4. More robust due to reasons 2 and 6.
5. Direct and simple sensing; data acquisition into a computer is more complex and costly (e.g., filter and amplifier, sample-and-hold, ADC).	5. More components (potentially less reliable) but operates even if a limit switch fails and provides perfect accuracy with respect to the remaining limit switches.
6. Entirely fails if the sensor (potentiometer) fails.	6. There is no issue of quantization error. The actual positions of the limit switches are determined precisely.
7. Quantization error is introduced when a sampled data value is digitized (represented in 3-bit form).	7. Relatively fast (a limit switch is binary). No further signal processing, sampling, and digitizing are needed.
8. Relatively slow (sensor time constant, signal conditioning, sampling, digitizing, and registering).	

Advantages of Digital Transducers:

1. They do not introduce quantization error.

2. Digital signals are less susceptible to noise, disturbances, or parameter variation in instruments because data can be generated, represented, transmitted, and processed as binary words consisting of bits, which possess two identifiable states (the noise threshold is half a bit).

3. Complex signal processing with very high accuracy and speed is possible through digital means (hardware implementation is faster than software implementation).

4. High reliability in a system can be achieved by minimizing analog hardware components.

5. Large amounts of data can be stored using compact, high-density data storage methods.

6. Data can be stored or maintained for very long periods of time without any drift or disruption by adverse environmental conditions.

7. Fast data transmission is possible through existing communication means over long distances with no attenuation and with less dynamic delays, compared to analog signals.

8. Digital signals use low voltages (e.g., 0–12 V dc) and low power.

9. Digital devices typically have low overall cost.