ME120 Experimental Methods
Pressure

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Absolute Pressure, Gage Pressure, and Vacuum

Then what is “differential pressure”?

\[ P_{\text{abs}} = P_{\text{gage}} + P_{\text{ambient}} \]

- **Absolute Pressure**
- **Gage Pressure**
- **Differential Pressure**
Pressure and Vacuum Units

- The SI unit of pressure is pascal (Pa), which is equivalent to a newton per square meter (N/m²), and as a point of reference one atmosphere (atm) is 101,325 Pa.

- In the United States, pounds per square inch (psi) is still extremely popular, and 1 atm is 14.7 psi.

- In some European countries, “bar” is still popular, and 1 bar = 100,000 Pa.

- For vacuum systems, “torr” is still very popular, and 1 torr = 1/760 atm = 1 mmHg ≈ 133 Pa.
Manometers

Manometers measure pressure based on the pressure differences in liquid columns.

\[
\frac{dp}{dz} = -\rho g \\
\int_{p_1}^{p_2} dp = -\rho g \int_{z_1}^{z_2} dz
\]

\[p_2 - p_1 = -\rho g (z_2 - z_1)\]

\[p_A = \rho gh_1\]

Factors affecting the accuracy:

- Scale
- Density of the liquid

Image(s) adapted from Fundamentals of Fluid Mechanics, 5th ed. by Munson, Young, & Okiishi, published by John Wiley & Sons, 2006
Manometer Variants

“barometer”

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Bourdon Gage

- A Bourdon gage uses the fact that an imbalance of pressure forces will tend to straighten a curved tube.

- Purely mechanical versions are inexpensive but relatively coarse.

- Improved resolution and accuracy can be attained by combining with displacement sensing.
Bourdon Gage Variants

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Pressure Transducers

- Pressure transducers commonly use mechanical structures that exhibit significant displacement when subject to applied pressure, and convert the displacement into an electrical signal.

- Examples of common position/strain sensing elements include:
  - Strain gages
  - Linear variable differential transducers
  - Capacitive sensors in “capacitance manometers”
  - Piezoelectric elements
  - Fiber optic reflection
Pressure Transducer Variants

- Expensive
- Durable

Low Pressure Applications (0.1Pa)

High frequency IC Engine applications
Silicon Pressure Sensor Examples

- Silicon pressure sensors are extremely practical because of manufacturing integration and great variety of packaging configurations for applications spanning automotive, aerospace, biomedical, etc.

- Manifestations vary, but almost all use a thinned silicon membrane that deforms with applied pressure.

- Many designs use diffusion to pattern piezoresistive elements, then interconnect in a (Wheatstone) bridge circuit.

SJSU MEMS Pressure Sensor Process Sequence

1. Grow oxide on silicon wafer
2. Wet etch backside cavity
3. Photo-pattern resistor regions (MASK 1)
4. Photo-pattern contact windows (MASK 3)
5. Plasma etch oxide and strip resist
6. Etch oxide/BSG and strip resist
7. Apply spin-on-glass
8. Evaporate aluminum
9. Drive dopant, form BSG, and further oxidize
10. Pattern metal lines (MASK 4)
11. Photo-pattern bulk-etch windows (MASK 2)
12. Etch aluminum and strip resist
13. Plasma etch oxide and strip resist
14. Plasma etch back oxide for anodic bonding
SJSU Microelectromechanical Systems (MEMS)
“High vacuum” is considered to be in the range of $10^{-3}$ to $10^{-6}$ torr.
“Low vacuum” actually corresponds to higher absolute pressure, greater than 1 torr.
“Ultrahigh vacuum” (UHV) represents the extreme below $10^{-9}$ torr.
Thermal Vacuum Gages

- Thermal vacuum gages use the fact that heat transfer between a gas and heated filament is dependent on molecule density...i.e. pressure.

- Thermocouple (T/C) gages place a thermocouple in contact with a heated filament to measure effectiveness of heat transfer.

- Pirani gages measure how the resistance of a filament changes with temperature in a Wheatstone bridge circuit.

\[ q = C (T_f - T_w) P_{vac} \]
Ionization Gages

- More extreme vacuum levels depend on monitoring ion flux.
- Ionized gases naturally depend on gas pressure and composition, so the current resulting from collection of positive ions at an electrode, for example, can be used to indicate pressure.
Sound and Pressure

From "Basic Concepts of Sound" lecture notes BA 7666-11
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Sound

- Sound is ultimately a pressure variation, so the underlying principles of sound measurement are similar to pressure measurement, although more inherently concerned with dynamics.

- For example, common condenser microphones use a membrane with capacitive displacement sensing.

- “Sound pressure” is the pressure above static pressure, but pressure itself is not very convenient for communicating with respect to common audible sounds.

- “Sound pressure level” on a logarithmic decibel scale is therefore more typically used.
Sound Pressure Level (SPL or \( L_p \))

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Sound Pressure Measurement

- @ 20deg C Vel of sound = 344m/sec
- Audible frequencies - 20 to 20000Hz
- Bruel & Kjaer 2236 Precision Integrating sound level meter
  - Condenser Microphone
    » Thin metal foil stretched like drumhead over a frame. Pressure changes > diaphragm movement > changes in capacitance > milli-volt signal > pre amplifier > other amplifier stages > A/D converter
    - Free-field response Microphone > one direction only
    - Random-incidence Microphone > Equally from all directions
Basics

- SPL is a measurement of sound strength on a logarithmic scale
- \[ L = \text{SPL} = 10 \log(\text{Signal Power}/\text{Ref Power}) \]
- \[ L = 10 \log (\text{Prms}/\text{Pref})^2 \]
- \[ L = 20 \log(\text{Prms}/\text{Pref}) \]
- Pref = Ref value for sound pressure in air = 20 micro pascals
- Sound level meter computes Prms in db based on sound pressure over a period of time
Decibel (dB)

\[ L_p = 20 \log \frac{p}{p_0} \text{ dB re } 20 \mu\text{Pa} \]

\[ (p_0 = 20 \mu\text{Pa} = 20 \times 10^{-6} \text{ Pa}) \]

**Fixed reference pressure**

**Ex. 1:** \( p = 1 \text{ Pa} \)

\[ L_p = 20 \log \frac{1}{20 \times 10^{-6}} \]

\[ = 20 \log 50 \, 000 \]

\[ = 94 \text{ dB} \]

**Ex. 2:** \( p = 31.7 \text{ Pa} \)

\[ L_p = 20 \log \frac{31.7}{20 \times 10^{-6}} \]

\[ = 20 \log 1.58 \times 10^{-6} \]

\[ = 124 \text{ dB} \]