MECHANCIAL MEASUREMENTS AND METROLOGY(BTME-3503)

Course Name: MMM

Semester: 5th

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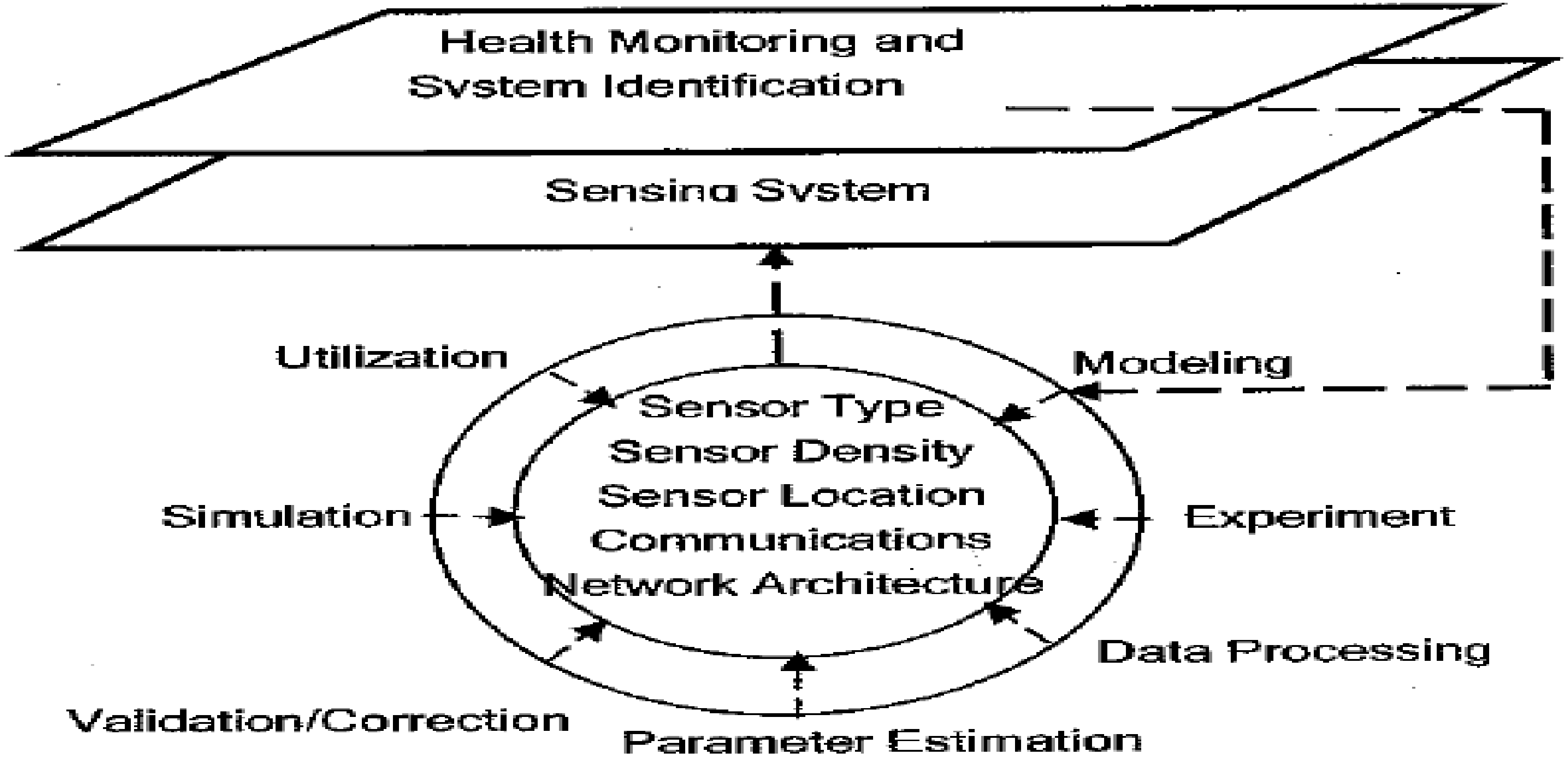
Sensors Terminology

- Transducer is a device which transforms energy from one type to another, even if both energy types are in the same domain.
  - Typical energy domains are mechanical, electrical, chemical, magnetic, optical and thermal.
- Transducer can be further divided into Sensors, which monitors a system and Actuators, which impose an action on the system.
  - Sensors are devices which monitor a parameter of a system, hopefully without disturbing that parameter

Classification of sensors

- Classification based on physical phenomena
  - Mechanical: strain gage, displacement (LVDT), velocity (laser vibrometer), accelerometer, tilt meter, viscometer, pressure, etc.
  - Thermal: thermal couple
  - Optical: camera, infrared sensor
  - Others …
- Classification based on measuring mechanism
  - Resistance sensing, capacitance sensing, inductance sensing, piezoelectricity, etc.
- Materials capable of converting of one form of energy to another are at the heart of many sensors.
  - Invention of new materials, e.g., "smart" materials, would permit the design of new types of sensors.

Paradigm of Sensing System Design



Instrumentation Considerations

- Sensor technology;
- Sensor data collection topologies;
- Data communication;
- Power supply;
- Data synchronization;
- Environmental parameters and influence;
- Remote data analysis.

Measurement

Measurement output:

• interaction between a sensor and the environment surrounding the sensor

• compound response of multiple inputs

Measurement errors:

• System errors: imperfect design of the measurement setup and the approximation, can be corrected by calibration

• Random errors: variations due to uncontrolled variables. Can be reduced by averaging.

Sensors

Definition: a device for sensing a physical variable of a physical system or an environment

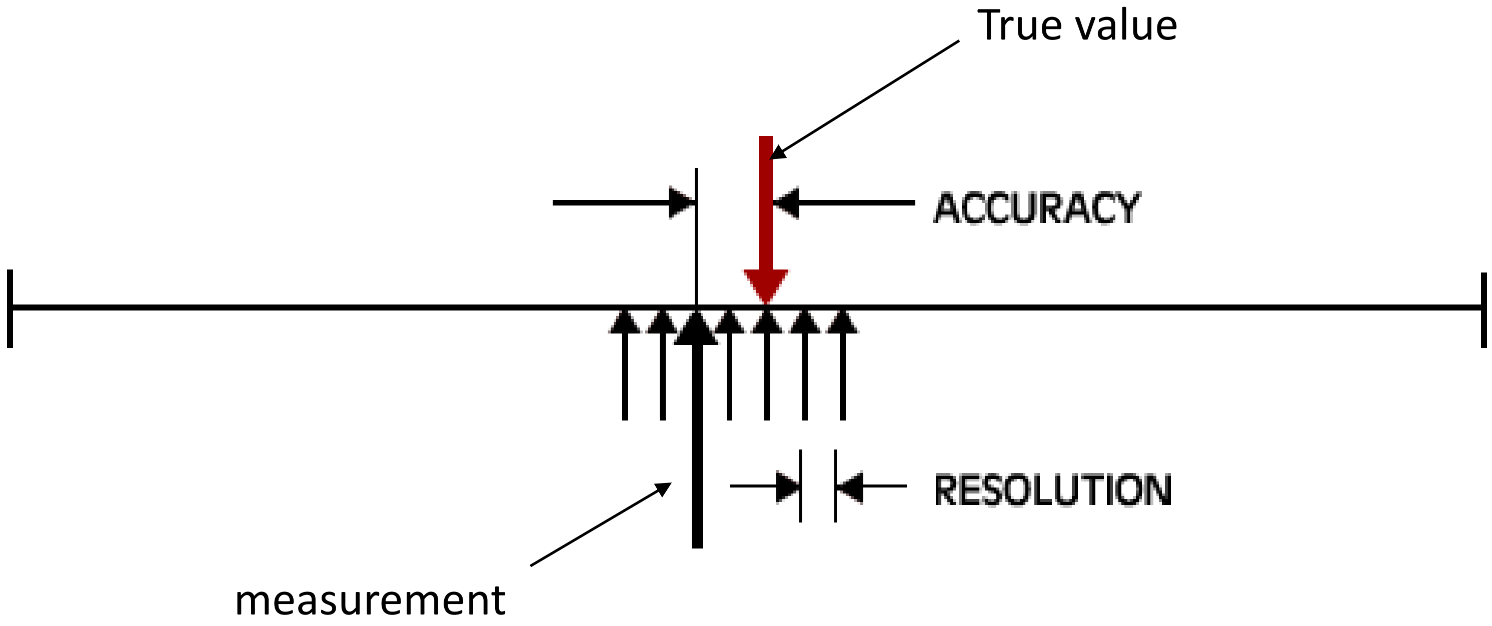
Classification of Sensors

- *Mechanical quantities*: displacement, Strain, rotation velocity, acceleration, pressure, force/torque, twisting, weight, flow
- Thermal quantities: temperature, heat.
- Electromagnetic/optical quantities: voltage, current, frequency phase; visual/images, light; magnetism.
- Chemical quantities: moisture, pH value

Specifications of Sensors

- **Accuracy:** error between the result of a measurement and the true value being measured.
- **Resolution:** the smallest increment of measure that a device can make.
- **Sensitivity**: the ratio between the change in the output signal to a small change in input physical signal. Slope of the input-output fit line.
- **Repeatability/Precision**: the ability of the sensor to output the same value for the same input over a number of trials

Accuracy vs. Resolution



Specifications of Sensor

- **Dynamic Range**: the ratio of maximum recordable input amplitude to minimum input amplitude, i.e. D.R. = 20 log (Max. Input Ampl./Min. Input Ampl.) dB
- **Linearity**: the deviation of the output from a best-fit straight line for a given range of the sensor
- **Transfer Function** (Frequency Response): The relationship between physical input signal and electrical output signal, which may constitute a complete description of the sensor characteristics.
- **Bandwidth**: the frequency range between the lower and upper cutoff frequencies, within which the sensor transfer function is constant gain or linear.
- **Noise**: random fluctuation in the value of input that causes random fluctuation in the output value

Attributes of Sensors

- **Operating Principle**: Embedded technologies that make sensors function, such as electro-optics, electromagnetic, piezoelectricity, active and passive ultraviolet.
- **Dimension of Variables**: The number of dimensions of physical variables.
- **Size**: The physical volume of sensors.
- **Data Format**: The measuring feature of data in time; continuous or discrete/analog or digital.
- **Intelligence**: Capabilities of on-board data processing and decision-making.
- **Active versus Passive Sensors**: Capability of generating vs. just receiving signals.
- **Physical Contact**: The way sensors observe the disturbance in environment.
- **Environmental durability**: will the sensor robust enough for its operation conditions

Strain Gauges

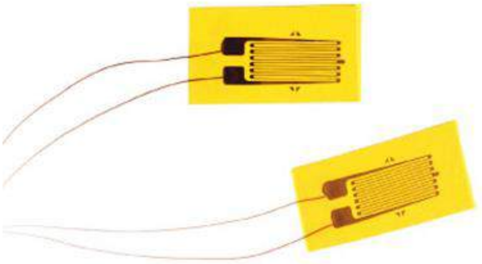
- Foil strain gauge
  - Least expensive
  - Widely used
  - Not suitable for long distance
  - Electromagnetic Interference
  - Sensitive to moisture & humidity

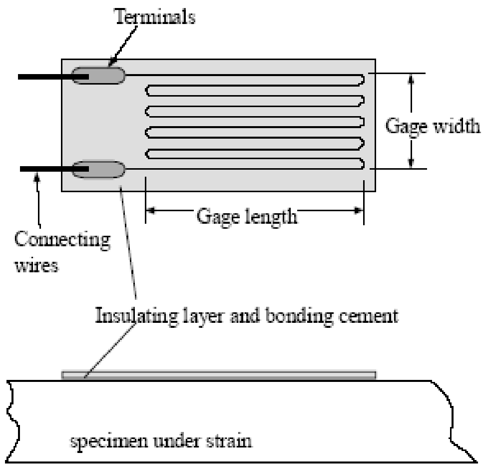
- Vibration wire strain gauge
  - Determine strain from freq. of AC signal
  - Bulky

- Fiber optic gauge
  - Immune to EM and electrostatic noise
  - Compact size
  - High cost
  - Fragile

Strain Sensing

- Resistive Foil Strain Gage
  - Technology well developed; Low cost
  - High response speed & broad frequency bandwidth
  - A wide assortment of foil strain gages commercially available
  - Subject to electromagnetic (EM) noise, interference, offset drift in signal.
  - Long-term performance of adhesives used for bonding strain gages is questionable
- Vibrating wire strain gages can NOT be used for dynamic application because of their low response speed.
- Optical fiber strain sensor





Strain Sensing

- Piezoelectric Strain Sensor
  - Piezoelectric ceramic-based or Piezoelectric polymer-based (e.g., PVDF)
  - Very high resolution (able to measure nanostrain)
  - Excellent performance in ultrasonic frequency range, very high frequency bandwidth; therefore very popular in ultrasonic applications, such as measuring signals due to surface wave propagation
  - When used for measuring plane strain, can not distinguish the strain in X, Y direction
  - Piezoelectric ceramic is a brittle material (can not measure large deformation)

Acceleration Sensing

- Piezoelectric accelerometer
  - Nonzero lower cutoff frequency (0.1 – 1 Hz for 5%)
  - Light, compact size (miniature accelerometer weighing 0.7 g is available)
  - Measurement range up to +/- 500 g
  - Less expensive than capacitive accelerometer
  - Sensitivity typically from 5 – 100 mv/g
  - Broad frequency bandwidth (typically 0.2 – 5 kHz)
  - Operating temperature: -70 – 150 C

Acceleration Sensing

- Capacitive accelerometer
  - Good performance over low frequency range, can measure gravity!
  - Heavier (~ 100 g) and bigger size than piezoelectric accelerometer
  - Measurement range up to +/- 200 g
  - More expensive than piezoelectric accelerometer
  - Sensitivity typically from 10 – 1000 mV/g
  - Frequency bandwidth typically from 0 to 800 Hz
  - ıperature: -65 – 120 C

Photo courtesy of PCB Piezotronics

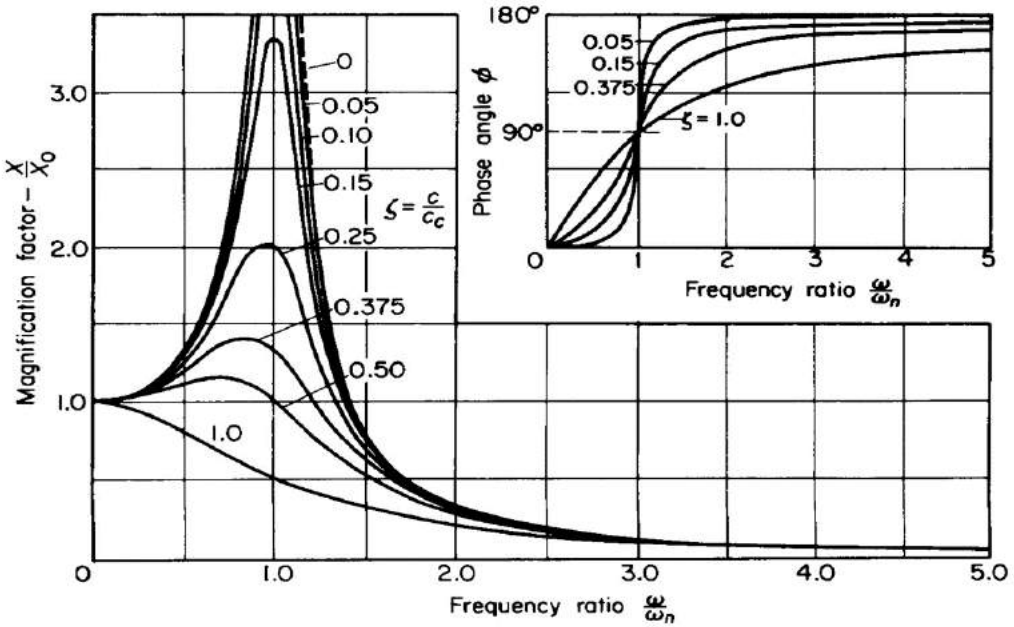


Fig. 3.1-3. Plot of Eqs. (3.1-8) and (3.1-9) for the vibration of a viscously damped system.

Force Sensing

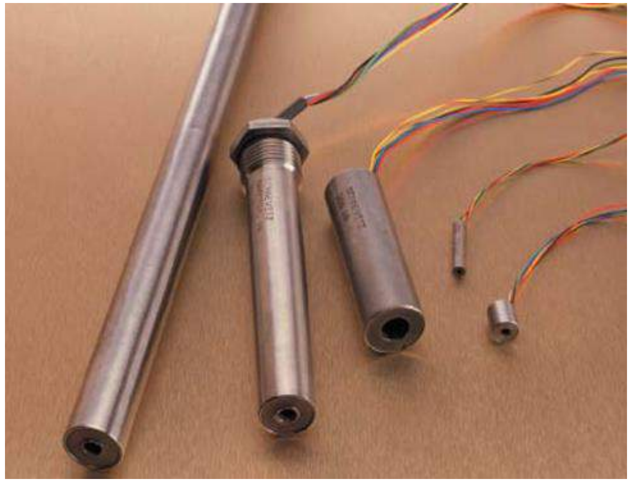
- Metal foil strain-gage based (load cell)
  - Good in low frequency response
  - High load rating
  - Resolution lower than piezoelectricity-based
  - Rugged, typically big size, heavy weight

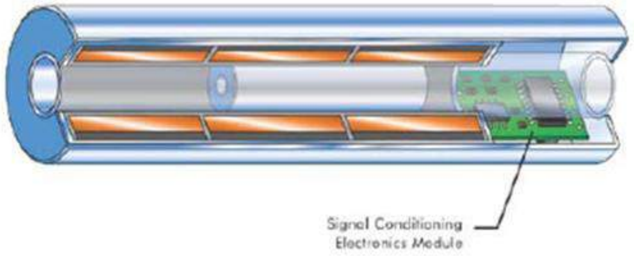
Force Sensing

- Piezoelectricity based (force sensor)
  - lower cutoff frequency at 0.01 Hz
    - can NOT be used for static load measurement
  - Good in high frequency
  - High resolution
  - Limited operating temperature (can not be used for high temperature applications)
  - Compact size, light

Displacement Sensing

- LVDT (Linear Variable Differential Transformer):
  - Inductance-based ctro mechanical sensor
  - "Infinite" resolution
    - limited by external electronics
  - Limited frequency bandwidth (250 Hz typical for DC-LVDT, 500 Hz for AC-LVDT)
  - No contact between the moving core and coil structure
    - no friction, no wear, very long operating lifetime
  - Accuracy limited mostly by linearity
    - 0.1%-1% typical
  - Models with strokes from mm's to 1 m available

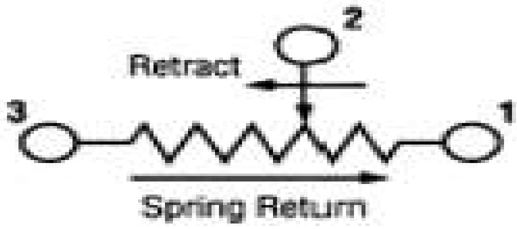




Displacement Sensing

- Linear Potentiometer
  - Resolution (infinite), depends on?
  - High frequency bandwidth (> 10 kHz)
  - Fast response speed
  - Velocity (up to 2.5 m/s)
  - Low cost
  - Finite operating life (2 million cycles) du wear
  - Accuracy: +/- 0.01 % - 3 % FSO
  - Operating temperature: -55 ~ 125 C

Photo courtesy of Duncan Electronics



Displacement Transducer

- Magneto strictive Linear Displacement Transducer
  - Exceptional performance for long stroke position measurement up to 3 m
  - Operation is based on accurately measuring the distance from a predetermined point to a magnetic field produced by a movable permanent magnet.
  - Repeatability up to 0.002% of the measurement range.
  - Resolution up to 0.002% of full scale range (FSR)
  - Relatively low frequency bandwidth (-3dB at 100 Hz)
  - Very expensive
  - Operating temperature: 0 – 70 C

Displacement Sensing

- Differential Variable Reluctance Transducers
  - Relatively short stroke
  - High resolution
  - Non-contact between the measured object and sensor

Type of Construction	Standard tubular
Fixing Mode	by 8mm diameter
Total Measuring Range	2(+/-1)mm
Pneumatic Retraction	No
Repeatability	0.1um
Operating Temperature Limits	-10 to +65 degrees C

Courtesy of Microstrain, Inc.

Velocity Sensing

- Scanning Laser Vibrometry
  - No physical contact with the test object; facilitate remote, mass-loading-free vibration measurements on targets
  - measuring velocity (translational or angular)
  - automated scanning measurements with fast scanning speed
  - However, very expensive (> $120K)

Photo courtesy of Bruel & Kjaer

Photo courtesy of Polytec

Summary

- From the above discussion on the topic of sensors and transducers, it has been pinpointed the use of advance systems in measurements for the rapidity in the field.
- Different types of sensors and transducers are discussed for measuring velocity, acceleration and force.

Topics to be Discussed in Next Lecture

Pressure and Flow measurements