Mechatronic Sensors

Topics

- Displacement Sensors
- Measurement of Acceleration and Vibration
- Velocity Measurements
- Angular Velocity Measurements
- Force Measurement
- Torque Measurements
- Mechanical Power Measurements

References

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Introduction

- Rapid advances in microprocessors
- Significant increase in electronically controlled devices and systems
- Systems require sensors and actuators
- Mechatronics—Integration of mechanical and electronic devices
  - Derived from “mechanical” and “electronic” and
- Methods and sensors for measurement of
  - Linear and rotary displacement
  - Acceleration and vibration
  - Velocity measurement
  - Force, load, torque, and mechanical power

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Displacement Sensors

- Displacement Sensors—Methods to measure position or displacement
- Key element in many mechatronic system
- Using
  - Potentiometric
  - Linear variable differential transformer (LVDT)
- Potentiometer—Device to measure linear or rotary displacement
- Increase in electrical resistance with displacement
- Wire-wound potentiometer: Sliding contact
- Rotary form: Numerous total revolutions
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#### Displacement Sensors

- Resolution limited by number of turns: Stepwise output
- Conductive plastic potentiometers
  - Developed to eliminate this stepwise output
  - Widely employed in mechatronic systems
  - Linear output with displacement
  - Typical linearity errors introduce
  - Instrument uncertainty from 0.2% to 0.02% of the reading
- Linear Variable Differential Transformers (LVDT)
  - Produces an AC output
  - Amplitude proportional to displacement of a movable core

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#### Displacement Sensors

**Potentiometer construction**
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Conductive plastic potentiometer

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Conductive plastic potentiometer
Construction of a linear variable differential transformer (LVDT)

Construction of a linear variable differential transformer (LVDT)
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#### Displacement Sensors

LVDT gauge head: Cross section of a typical LVDT gauge head

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#### Displacement Sensors

- Rotary variable differential transformer (RVDT)
- Angular displacement measurements
- Linear output range approximately ±40 degrees
Rotary variable differential transformer
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Measurement of Acceleration and Vibration

❖ Range of applications for acceleration and vibration measurements
  ❑ E.g., machine design
  ❑ E.g., guidance systems
❖ Wide variety of transducers and measurement techniques
❖ Displacement, velocity, and acceleration measurements also referred to as shock or vibration measurements
❖ Seismic Transducer—System with output direct indication of either displacement or acceleration
  ❑ A spring-mass damper system
  ❑ A protective housing
  ❑ Appropriate output transducer

Seismic transducer rigidly attached to object experiencing the motion
Seismic transducer

Response of a seismic Transducer to a constant acceleration
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Measurement of Acceleration and Vibration

Response of a seismic Transducer to a constant acceleration

- Transducers for Shock and Vibration Measurement
- Destructive forces generated by vibration and shock best quantified through measurement of acceleration
- Widely employed for measurement of shock and vibration
  - Strain gauge
  - Piezoelectric transducers
- Piezoelectric accelerometer—Principles of a seismic transducer through the use of a piezoelectric element
- Upward or downward motion resulting in appropriate signal
- Range of frequency response from 0.03 to 10,000 Hz
- Static sensitivity range from 1 to 100 mV/g
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**Measurement of Acceleration and Vibration**

![Basic piezoelectric accelerometer](image)

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**Velocity Measurements**

- Linear and angular velocity measurements
- Utilize a variety of approaches
  - Radar and laser systems for speed measurement
  - Mechanical counters to provide an indication of a shaft rotational speed
- Displacement, velocity, and acceleration measurements made with respect to some frame of reference
- Velocity directly measured by mechanical means only over very short times or small displacements: Limitations in transducers
- Displacement measured at identifiable time intervals: Velocity determined through differentiation of displacement
If acceleration is measured: Velocity determined from integration of the acceleration signal
Moving coil transducers—Voltage generated when a conductor experiences a displacement in a magnetic field
Same phenomenon used to generate electric power in generators and alternators
Output voltage proportional to coil velocity
Output polarity indicates velocity direction
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Angular Velocity Measurements

- Measurement of angular velocity: Wide range of applications
- E.g., speedometers on automobiles
- Centripetal acceleration of the flyball masses: Steady-state displacement of spring
  - Spring force proportional to square of angular velocity
- Stroboscopic angular velocity measurements
  - Stroboscopic light source
  - High-intensity flashes of light occur at a precise frequency
  - Intermittent observation of a periodic motion
  - Appears to stop or slow the motion
  - Uncertainties to less than 0.1%

Mechanical angular velocity sensor
Images resulting from harmonic and subharmonic flashing rates for stroboscopic angular speed measurement
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Angular Velocity Measurements

- Electromagnetic techniques
  - Rotational velocity utilize transducers
  - Generate electrical signals
  - Indicative of angular velocity

- Angular velocity found either from amplitude or frequency of the output signal

Angular velocity measurement employing a toothed wheel and magnetic pickup
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**Force Measurements**

- Measurement of force is most familiar as the process of weighing
  - Ranging from weighing micrograms of a medicine
  - To weighing trucks on the highway
- Load cell—A transducer that generates a voltage signal as a result of an applied force
  - Along a particular direction
- Force transducers often consist
  - Elastic member
  - Deflection sensor

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**Force Measurements**

- Deflection sensors employ changes to sense deflection
  - Capacitance
  - Resistance
  - Piezoelectric effect
- Load cell types
  - Strain Gauge Load Cells
  - Piezoelectric Load Cells
  - Proving Ring
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#### Force Measurements

- Strain gauge load cells
- Constructed of a metal
- Shape such that range of forces to be measured results in a measurable output voltage
- Characterized as
  - Beam-type load cells
  - Proving rings
  - Columnar-type
- Sensing element functions as a cantilever beam
- Strain gauges are mounted on top and bottom
- Measure normal or bending stresses

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#### Elastic load cell designs

- Column
- Column with stress concentration
- Hollow column
- Frame
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Bending beam load cell and stress distributions

Shear beam load cell and shear stress distribution
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Typical load cells

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Typical load cells
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Typical load cells

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Force Measurements

- Piezoelectric Load Cells
- Piezoelectric materials: Develop a charge when subject to a mechanical strain
- Most common piezoelectric material: Single-crystal quartz
- Static sensitivities ranging from 0.05 to 10 mV/N
- Frequency response up to 15,000 Hz
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Force Measurements

- Proving Ring
- A ring-type load cell
- Calibration of materials testing machines
- Because of the high degree of precision and accuracy
- Measuring deflection of the ring in direction of applied force

Ring type load cell, or proving ring
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**Torque Measurements**

- Torque and mechanical power measurements
  - Often associated with the energy conversion processes
  - Provide mechanical and electrical power
- Mechanical power transmission occurs through torque acting through a rotating shaft
  - From automobiles to turbine-generator sets
- Strain-gauge–based torque cells
  - Constructed similar to load cells
  - Torsional strain in an elastic element is sensed
  - By strain gauges appropriately placed on elastic element

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**Shaft instrumented for torque measurement**
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**Mechanical Power Measurements**

- Prime movers such as internal combustion (IC) engines and gas turbines
  - Convert chemical energy in a fuel to thermodynamic work
  - Transmitted by a shaft to the end use
- Power transmitted through a mechanical coupling
- Measurement of such mechanical power transmission
- Prony brake—Used to measure shaft power
- Power measured by recording torque acting on torque arm and rotational speed of the engine
- Prony brake: Example of an absorbing dynamometer
- Dynamometer—Device that absorbs and measures the power output of a prime mover

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**Mechanical Power Measurements**

- Dynamometer
  - Power absorption ratings above 200 HP
  - Top speed of 120 MPH
- American Society of Mechanical Engineers (ASME)
  - Performance Test Code (PTC) 19.7
  - Guidelines for measurement of shaft power
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Mechanical Power Measurements

![Diagram of a Prony brake](image)

Prony brake