Industrial Sensors

- Proximity
  - Mechanical
  - Optical
  - Inductive/Capacitive
- Position/Velocitiy
  - Potentiometer
  - LVDT
  - Encoders
  - Tachogenerator
- Force/Pressure
- Vibration/acceleration
Definitions

- **Accuracy**: The agreement between the actual value and the measured value
- **Resolution**: The change in measured variable to which the sensor will respond
- **Repeatability**: Variation of sensor measurements when the same quantity is measured several times
- **Range**: Upper and lower limits of the variable that can be measured
- **Sensitivity and Linearity**

Proximity Sensors

- Widely used in general industrial automation
  - Conveyor lines (counting, jam detection, etc)
  - Machine tools (safety interlock, sequencing)
- Usually digital (on/off) sensors detecting the presence or absence of an object
- Consist of:
  - Sensor head: optical, inductive, capacitive
  - Detector circuit
  - Amplifier
  - Output circuit: TTL, solid state relay

Mechanical Proximity Switches

- Essentially a mechanical switch
- On/off operation only
- Two general modes
  - Normally Open (NO)
  - Normally Closed (NC)
- Come in a wide variety of mechanical forms
- For a wide range of uses

Example Mechanical Proximity Switches
**When to Use Mechanical Proximity Switches**

- Where physical contact is possible
- Where definitive position is required
- In operation-critical or safety-critical situations
- Where environment conditions preclude the use of optical or inductive sensors

**Applications and Use of Mechanical Proximity Switches**

- Easy to integrate into machinery of all types
- Requires contact (thus wear)
- Range of voltages: DC 0-1000V, AC, etc.
- Very robust (explosion proof if required)
- Usually used as:
  - Limit switch
  - Presence/absence indicator
  - Door closed/open

**Places You Find Mechanical Proximity Switches!**

**Optical Proximity Sensors**

- Consist of a light source (LED) and light detector (phototransistor)
- Modulation of signal to minimize ambient lighting conditions
- Various models: 12-30V DC, 24-240V AC, power
- Output: TTL 5V, Solid-state relay, etc.
Operational Modes

- **Through Beam:**
  - Long range (20m)
  - Alignment is critical!

- **Retro-reflective**
  - Range 1-3m
  - Popular and cheap

- **Diffuse-reflective**
  - Range 12-300mm
  - Cheap and easy to use

Example Optical Proximity I

Example Optical Proximity II

When to use an Optical Proximity Sensor

- **Pros**
  - Non-contact, no moving parts, small.
  - Fast switching, no switch bounce.
  - Insensitive to vibration and shock
  - Many configurations available

- **Cons**
  - Alignment always required
  - Can be blinded by ambient light conditions (welding for example)
  - Requires clean, dust and water free, environment
Applications of Optical Proximity Sensors

• Stack height control/box counting
• Fluid level control (filling and clarity)
• Breakage and jam detection
• And many others…

http://www.omron-ap.com/application_ex/index.htm
http://www.sick.de/english/products/products.htm
http://content.honeywell.com/sensing/prodinfo/

Other Optical Devices

Ultrasonic Proximity Sensors

• Use sound pulses
• Measures amplitude and time of flight
• Range provides more than on/off information
• Frequencies 40KHz-2MHz

When to use Ultrasonic Sensors

• Provide range data directly:
• Level monitoring of solid and liquids
• Approach warning (collisions)
• Can (usually) work in heavy dust and water
• Ambient noise is potentially an issue

http://www.automationsensors.com/
Example Applications

Car Wash Application

Paper roll Thickness Monitor

Waste water flow volume

Example Inductive Sensors I

Detection of open/close functions

Detection of rotation

Example Inductive Sensors II

Bulk mounted inductive sensors. Detect presence of object without contact. Range 3mm +/- 10%

Inductive and Capacitive Proximity Sensors

• Inductive sensors use change in local magnetic field to detect presence of metal target
• Capacitive Sensors use change in local capacitance caused by non-metallic objects
• Generally short ranges only
• Regarded as very robust and reliable
Example Capacitive Sensors

Panel Mounted Capacitive Sensor. Can detect wood, plastic, and metal. Range 3mm-25mm.

Flat mounted Capacitive Sensor. Used for detecting panels of glass. Range = 10mm +/- 10%.

Position and Velocity Sensors

• Position and velocity measurement is often required in feedback loops.
• For positioning, and velocity control.
• Position measurement:
  – Potentiometers
  – LVDT
  – Encoders
• Velocity Measurement:
  • Tachometer

Potentiometers

An analog sensor Works as a voltage divider.

Types of Potentiometer

• Wirewound
  – Wiper slides along coil of Ni-chrome wire
  – Wire tends to fail, temperature variations
• Cermet
  – Wiper slides on conductive ceramic track
  – Better than wire inmost respects
• Plastic film
  – High resolution
  – Long life and good temperature stability
Linear Potentiometers

When to use a Potentiometer

- **Pros**
  - Require analog signal for control
  - Require absolute positional information
  - Low cost
- **Cons**
  - Temperature and wear variations
  - Not in dusty or wet environments

Linear Variable Differential Transformer (LVDT)

- An LVDT consists of a magnetic core that moves in a cylinder
- The sleeve of the cylinder contains a primary coil that is driven by an oscillating voltage
- The sleeve also contains two secondary coils that detect this oscillating voltage with a magnitude equal to displacement
- The automatic nulling that can be achieved using two coils makes LVDTs very accurate (submillimetre)

LVDT Signal Conditioning

- Uses AC modulation, demodulation and phase comparison
- Available in a single monolithic package
Example LVDTs

Free core LVDTs for use in hostile environments
And total immersion

Spring-loaded
Standard for use
In hydraulic cylinders

When to use an LVDT

• High accuracy
• Linear operation (synchro resolver is equivalent rotary LVDT)
• Harsh environment
• Analog position control
• Embedding (in cylinder for example)

Optical Encoders

• Encoders are digital Sensors commonly used to provide position feedback for actuators
• Consist of a glass or plastic disc that rotates between a light source (LED) and a pair of photo-detectors
• Disk is encoded with alternate light and dark sectors so pulses are produced as disk rotates

Encoder Internal Structure
Incremental Encoders

- Pulses from leds are counted to provide rotary position
- Two detectors are used to determine direction (quadrature)
- Index pulse used to denote start point
- Otherwise pulses are not unique

Absolute Encoders

- Absolute encoders have a unique code that can be detected for every angular position
- Often in the form of a “grey code”; a binary code of minimal change
- Absolute encoders are much more complex and expensive than incremental encoders

Encoder processing

- Need a squaring circuit to digitise signal
- A counter and index monitor
- Generally available in monolithic form
- Often with algorithms for control externally programmable

When to Use an Encoder

- Require accurate position information:
  - 10,000 line incremental
  - 360 line absolute
- Digital feed-back loop
- Compact and reasonably rugged (not as good as inductive)
- Linear encoders also available
**Tachometers**

- Measurement of rotary speed using a DC generator
- Essentially a motor running in reverse
- Used to be common to have these attached to motors to enable direct analog feedback
- Much less common now with digital control (use incremental encoders)

![Tachometer Image](Image)

**Force and Pressure**

- Force and Pressure generally measured indirectly through deflection of an alternate surface
- Mechanism include:
  - Physical motion and measurement using (eg) an LVDT
  - Strain gauges (metal that changes resistance when stressed)
  - Piezo electric materials that generate a current when deformed

**LVDT Load Cell**

![LVDT Load Cell Diagram](Image)

**Strain Gauge Bridge**

- Strain Gauges: $\frac{V_{\text{meas}}}{V_{\text{exc}}} = \frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}$
- Tension: $\Delta R = R \cdot GF \cdot \varepsilon$
- $GF = \frac{\Delta R / R}{\Delta L / L}$
- $\Delta R = R \cdot GF \cdot \varepsilon$
- $\varepsilon = -\frac{4V_{\text{meas}}}{GF \left(2V_{\text{meas}} - V_{\text{exc}}\right)}$
Example Load Cells

- Subminiature Load cells
- Reaction torque load cell
- Axial load cell

http://www.entran.com/ltoc.htm

Sub-miniature Load cells

- All signal conditioning and amplification integrated with the sensor
- Load cell bridge structure

Piezo Load Cells

- Distortion of crystal, either quartz or BaTiO$_3$
- Used for accurate measurement of small loads
- Come in the form of:
  - single axis load washers
  - or multiple axis load washers and tables

Pressures

- Pressure measured by:
  - Pitot tube and
  - Deformation of fixed membrane
- Deformation measured using same methods as for force:
  - Spring (manometer)
  - Piezo distortion
  - Strain gauges

- Miniature
- Industry IP69
- High Temperature
**Acceleration**

- Acceleration is also measured via the force exerted by an accelerating mass
- Distortion of a piezo
- Motion of a cantilever
- Strain on mass restraints
- Accelerometers mainly used to measure vibration

**Tri-axial Accelerometers**

- Triaxial accelerometers used in mobile systems
  - In high-performance cars
  - Inside rotating elements of turbines
  - In aircraft elements
- Provide vibration information
- Provide short-term position data

**Silicon Machined Accelerometers**

- Used in eg air-bags

**Silicon Gyroscopes**

- Structural arrangement of silicon which records centrifugal acceleration and thus angular speed
- Use strain-gauge bridges and/or piezo structure to record deformations
- Multiple component elements to calibrate other accelerations
Inertial Systems

- Many different types of accelerometer and gyroscope systems
- Mechanical bodies, fibre optic, etc
- Together in an orthogonal arrangement of accelerometers and gyroscopes, these comprise an inertial measurement unit (IMU)
- An IMU that is used for navigation is called an inertial navigation system (INS)
- These are widely used in aircraft and missile navigation and guidance

Summary

- There are many types of sensors available today
- Selecting the right sensor is a critical part of the design cycle
- Requires an understanding of
  - Type of motion
  - Precision of motion
  - Magnitude of motion
  - Operating conditions