Sensors

Introduction

A sensor is a device that produces a measurable response to a change in a physical condition, such as temperature or thermal conductivity, or to a change in chemical concentration. Sensors are particularly useful for making in-situ measurements such as in industrial process control.

Sensors are an important part to any measurement and automation application. The sensor is responsible for converting some type of physical phenomenon into a quantity measurable by a data acquisition (DAQ) system.

Choosing a Sensor

Factors to consider when choosing a sensor.

- **Accuracy** - The statistical variance about the exact reading.
- **Calibration** - Required for most measuring systems since their readings will drift over time.
- **Cost**
- **Environmental** - Sensors typically have temperature and/or humidity limits.
- **Range** - Limits of measurement or the sensor.
- **Repeatability** - The variance in a sensor's reading when a single condition is repeatedly measured.
- **Resolution** - The smallest increment the sensor can detect.

Types of Sensors

Sensors are used to measure basic physical phenomena including:

1. **Acceleration - Shock & Vibration.**
2. **Angular / Linear Position**
3. **Chemical/Gas Concentration**
4. **Humidity**
5. **Flow Rate**
6. **Force**
7. **Magnetic Fields**
8. **Pressure**
9. **Proximity - Spatial Presence**
10. **Sound**
11. **Temperature**
12. **Velocity**

Sensors: Acceleration

Acceleration

An **accelerometer** is an electromechanical transducer which produces at its output terminals, a voltage or charge that is proportional to the acceleration to which it is subjected. The piezoelectric elements (similar to small crystals) within the accelerometer have the property of producing an electrical charge which is directly proportional to the strain and thus the applied force when loaded either in tension, compression or shear.

Accelerometers

Applications include measurement of Acceleration, Angular Acceleration, Velocity, Position, RPM or Angular Rate, Frequency, Impulse and Impulse Energy, Force, Tilt and Orientation, and Motion Detection.

Sensors: Linear / Angular Position

Linear / Angular Position

Potentiometers

Servo Potentiometer

Potentiometers utilize a variable resistor to convert an angle or displacement to a resistance/voltage. They operate by moving a contact along a resistor to produce a voltage proportional to the position.

Encoders

An encoder is a sensor of mechanical motion. It translates motion (such as position, velocity, and acceleration) into electrical signals.

Rotary Encoder

Absolute encoders have a unique value for each mechanical position and thus the position is known "absolutely". With this type of encoder, the position information is never lost and is instantly available as a digital word on power-up.

Sensors: Chemical / Gas Concentrations

Chemical / Gas Concentrations

There are many different types of sensors for detection concentration levels of chemicals and gasses. These sensors are critical for safety considerations in many industrial applications.

Following is a table providing a brief summary of sensor types and applications.

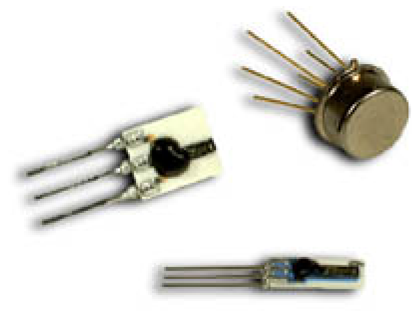
Catalytic Sensor

Sensor type	Detectable gases	Usable range	Pro's	Con's
Electrochemical	Toxics, oxygen	ppm levels	Low power, accurate, repeatable	3 year lifetime slightly lower at high temps; some types are cross-sensitive
Pellistor	Flammables	LEL levels	Generally good in all ways; portable	Can be damaged by high levels of H2S, but poison resistant types are available
Infrared	Flammables and CO2	0.1 (or less) to 100% by volume	Fail safe; generally excellent	Expensive (but getting cheaper); non-portable
Thermal Conductivity	Many, at % levels, including binary mixtures	% levels	20 year life (at least); stable; can detect inert gases	Only appropriate for certain gases

Sensors: Humidity

Humidity

Humidity sensors are used to measure the humidity in air, as a fraction of the maximum amount of water that can be absorbed by air at a certain temperature. Under normal atmospheric conditions and a given temperature this fraction can vary between 0 (absolute dry point) and 100 (Condensation starting point). This relative humidity measurement is only valid under the above mentioned temperature and atmospheric conditions, thus making very important the fact that the sensor must not be affected by temperature or pressure changes. As a result it is obvious that Temperature or Pressure Dependent sensing elements, such as Mechanical Devices and Resistive type Sensors, are far behind of the respective non-dependent ones, such as Capacitance sensors. Absorption based humidity sensors provide both temperature and %RH (Relative Humidity) outputs.



Humidity Sensors

Humidity Cells are mainly Capacitance sensors characterized of an excellent long term stability, good resistance to pollutants, precise measurments, high sensitivity, intergangeability and wettability.

Applications Include:

1. Refrigeration
2. Drying Processes
3. Meteorology
4. Battery-powered systems
5. OEM assemblies

Sensors: Flow Rate

Flow Rate

Venturi Valves

Flow Rate Sensor

A Venturi valve reduces the cross section of a pipe to create a pressure differential from the normal pipe diameter. The pressure differential increases with the velocity of the flow to aid in determining the flow rate.

Transit-Time Flow Measurement Principle

A transit-time flowmeter measures the effect of a liquid's flow velocity on bi-directional acoustical signals. An upstream transducer (T1) sends a signal to a downstream transducer (T2) that in turn sends a signal back. When there is no flow, the time to go from the T1 to T2 is the same as the time going from T2 to T1. However, when there is flow, the effect of the liquid's flow velocity on the acoustical signal is to assist the signal in the up to downstream direction and hinder the signal in the down to upstream direction. This creates the time difference by which the liquid's flow velocity, and ultimately the flowrate, is determined.

Pitot Tubes

Pitot tubes have been used in flow measurement for years. Conventional pitot tubes sense velocity pressure at only one point in the flowing stream. Therefore, a series of measurements must be taken across the stream to obtain a meaningful average flow rate.

Flow Transducers

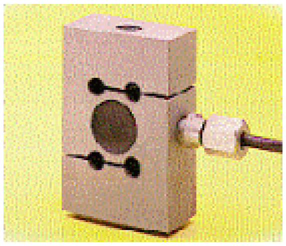
Fluid flowing through the sensor spins a magnetic rotor to induce a voltage in a coil. An electronic circuit measures the frequency of the electrical pulses generated and computes the flow rate. This rate is converted to a 0-5 VDC or 0-20 MA output proportional to the flow rate and also used to control a relay. The relay trip point may be preset at the factory or adjusted by the user by turning a potentiometer.

Sensors: Force

Force

Load Cells / Force Transducers

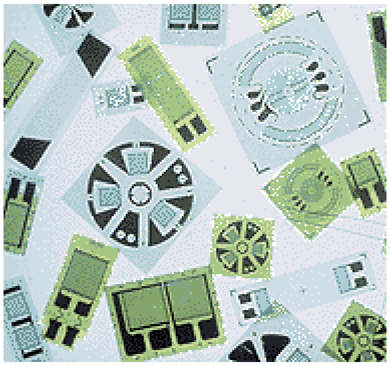
Load Cells are intended for determination of static or dynamic tensile and compressive loads and come in many different forms including compression, tension, simple beam and single point. Force transducers can be used as load cells, but can also be used in weighing applications and measuring compression or tension. Load cells can be built utilizing either transducers, LVDTs, strain gauges or piezoelectric sensors.



Tension Load Cell

Strain Gauges

Strain gauges are used for the measurement of tensile and compressive strain in a body and can therefore pick up expansion as well as contraction. Strain is caused in a body by internal or external forces, pressures, moments, heat, or structural changes in the material. In general, most types of strain gages depend on the proportional variance of electrical resistance to strain: the piezoresistive or semi-conductor gage, the carbon-resistive gage, the bonded metallic wire, and foil resistance gages.



Strain Gauges

The bonded resistance strain gage is by far the most widely used in experimental stress analysis. They typically consist of a grid of very fine wire or foil bonded to the backing or carrier matrix. The carrier matrix attaches to test specimens with an adhesive. When the specimen is mechanically stressed (loaded), the strain on the surface is transmitted to the resistive grid through the adhesive and carrier layers. The strain is then found by measuring the change in resistance.

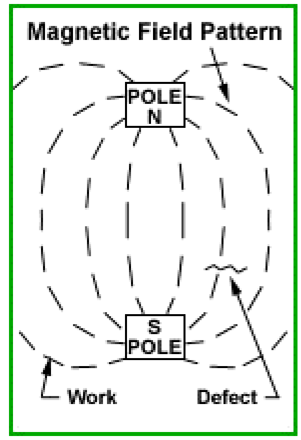
The bonded resistance strain gage is low in cost, can be made with a short gage length, is only moderately affected by temperature changes, has small physical size and low mass, and has fairly high sensitivity to strain.

Sensors: Magnetic Fields

Magnetic Fields

Magnetoresistive (MR) Sensors

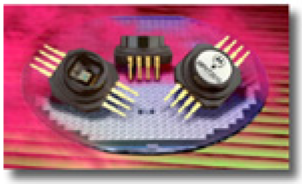
Magnetoresistive sensors can determine the change in earth's magnetic field due to the presence of a ferromagnetic object or position within the earth's magnetic field. The high bandwidth allows detection of vehicles and other ferrous objects at high speeds. The sensors are contactless and the working distance is dependent on the ferromagnetic mass it is measuring. Applications include Compassing and Navigation, Vehicle Detection, Virtual Reality, Laboratory Instrumentation, Medical Instruments, Underground Boring Equipment and Flux Gate Replacement.



Sensors: Pressure

Pressure Transducer

Pressure sensor applications include flow (HVAC), height of a column of liquid, altitude, depth of a submerged object, position, sound (dbspl), barometric pressure, map, pressure drop, vacuum, volumetric displacement, and weight.



Pressure Transducer - Motorola

A **transducer** is simply a device (or medium) that converts energy from one form to another. The term is generally applied to devices that take physical phenomenon (pressure, temperature, humidity, flow, etc.) and convert it to an electrical signal.

Pressure transducers/sensors use a wide range of operating principles including:

1. **Motion transducers** use a bellows or Bourdon tube to convert pressure to an output. In one common type, the LVDT, an inductive member is driven into or out of a coil. It contains numerous pivots and linkages, making it nonlinear and susceptible to wear and vibration, but it has the advantage of inherently high output.
2. **Pressure potentiometers** have characteristics similar to those of LVDTs. In this case, a wiper is driven across a resistive coil, with output determined by wiper position. Compared to an LVDT, it has the added disadvantage of coil wear. If continuously operated in about the same pressure range, it may suddenly short out or produce severely nonlinear output. These sensors are rather inexpensive.
3. **Silicon or "chip" transducers** are widely used in high-volume applications. There are two types of silicon pressure sensors, capacitive and piezoresistive. Capacitive devices are much more stable, sensitive, and temperature resistant. Piezoresistive types are easier to make and cost less and therefore dominate the market.
4. **Capacitance transducers** use a flexing diaphragm to produce capacitance changes proportional to applied pressure. Because of their low price, a common application of these devices is in automobiles. One drawback is at normal hydraulic pressure their operation dictates a large diaphragm making them better suited to low-pressure systems.
5. **Piezoresistive Sensors** are available in both gage and absolute versions. The sensor typically consists of a Wheatstone bridge etched on a silicon diaphragm which outputs a voltage that is proportional to pressure.
6. **Electropneumatic transducers** are used to provide regulated air pressures for the control of process systems. Typically, electropneumatic transducers are of three basic types: voice-coil beam, voice-coil beam dampened by an oil dashpot, and torque motor.
   - **Voice-coil beam transducers** use a nozzle/flapper arrangement to convert a small mechanical motion into a proportional pneumatic signal.
   - **Damped transducers** operate in a similar manner except that the arm controlling flapper position is attached to a float suspended in silicone oil.
   - **Torque-motor transducers** also have similar operating principles, except that a conventional torque motor replaces the voice-coil beam arrangement to position the flapper.

Sensors: Proximity

Proximity - Spatial Presence

Proximity Sensors

1. **Inductive Proximity Sensors**

   Turck Proximity Sensors

   Inductive proximity sensors are widely used in the modern high speed process control environment for the detection, positioning and counting of ferrous and non-ferrous metal objects. Due to the method of construction and superior performance of inductive sensors, they are increasingly used to replace the traditional limit switch, thus upgrading speed and reliability of existing machinery.

   Principle of Operation

   Inductive proximity sensors respond to ferrous and non - ferrous metal objects. They will also detect metal through a layer of non - metal material. An inductive sensor consists of an oscillator circuit (ie. the sensing part) and an output circuit including a switching device (eg. transistor or thyristor), all housed in a resin encapsulated body. An essential part of the oscillator circuit is the inductance coil creating a magnetic field in front of the sensing face. When the magnetic field is disturbed, the output circuit responds by either closing the output switch (normally open version type NO) or by opening the output switch (normally closed version type NC).

2. **Capacitive Sensors**

   Capacitive sensors are often successfully used in applications which cannot be solved with other sensing techniques. Capacitive sensors respond to a change in the dielectric medium surrounding the active face and can thus be tuned to sense almost any substance. Capacitive sensors can, also, sense a substance through a layer of glass, plastic or thin carton.

   Some typical applications for capacitive sensors are:

   1. Level control of non-conductive liquids (oil, alcohol, fuel).
   2. Level control of granular substances (flour, wheat, sugar).
   3. Sensing substances through a protective layer (eg. glass).

   The fact that capacitive sensors respond to most substances, necessitates some care during the installation, adjustment and long term operation of the sensor. The sensitivity of capacitive sensors is affected by the moisture content and the density of the substance to be sensed.

Deposits of excessive dust and dirt on or around the sensing face of the sensor, cause erratic response and hence the sensor may require periodic cleaning if used in a polluting environment.

Principle of Operation

Capacitive sensors respond to any substance with a high dielectric constant (water, oil, fuel, sugar, paper) without necessarily making physical contact. They are less suitable for polystyrene and similar low density substances. Operation is based on an internal oscillator with two capacitive plate-electrodes, tuned to respond when a substance approaches the sensing face. When the target is sensed, the output switch will either close to activate a load for a normally open option or the switch will open to de-activate the load for a normally closed option. The LED will illuminate when the output switch closes.

3. **Photoelectric or Opto-electronic Sensors**

Photoelectric sensors offer non-contact sensing of almost any substance or object up to a range of 10 meters. Photoelectric sensors consist of a light source (usually an LED, light emitting diode, in either infrared or visible light spectrum) and a detector (photodiode). Due to the high intensity infra-red energy beam, these sensors have major advantages over other opto-electronic systems when employed in dusty enviroments. With their focused beam and long range, opto-electronic sensors are increasingly used in applications where other sensing techniques are lacking in sensing distance or accuracy.

Photoelectric sensors are available in a variety of modes including:

- **Infrared Proximity (Diffuse Reflective)**

  Proximity type photoelectric sensors detect the light reflected by the target itself. Proximity photoelectric sensors are preferable for general purpose sensing applications, particularly where the detected object is only accessible from one direction.

- **Transmitted Beam (Thru-beam)**

  Transmitted beam photoelectric sensors use separate infrared transmitters and receivers. Objects passing between the two parts interrupt the infrared beam, causing the receiver to output a signal.

- **Retroreflective (Reflex)**

  Retroreflective photoelectric sensors operate by sensing the light beam that is reflected back from a target reflector. As with thru beam models, objects which interrupt the beam activate an electronic output.

- **Polarized Retroreflective (Polarized Reflex)**

  Polarized retroreflective sensors work like normal retroreflective sensors but use a polarizing filter in front of the transmitter and receiver optics. These filters are designed so that shiny objects are reliably detected.

- **Fiber Optic**

  Fiber optic sensors use fiber optic cable to conduct light from the LED to the sensing area, and another cable to return light from the sensing area to the receiver. By using fiber optic cables, the electronics can be protected from hostile environments such as temperature extremes and harsh chemicals. Fiber optics also allow sensing in extremely confined spaces.

- **Background Rejection**

  STI's background rejection sensors use a special arrangement of two sensing zones: the near-field zone is where objects can be detected, the far-field zone is where objects cannot be detected. There is an extremely sharp cut-off between these zones. The cut-off range is adjustable. These sensors are ideal for applications where background objects need to be ignored.

Ultrasonic sensors

Ultrasonic sensor utilize the reflection of high frequency (20KHz) sound waves to detect parts or distances to the parts. The two basic ultrasonic sensor types are:

0. Electrostatic - Uses capacitive effects for longer range sensing and wider bandwidth with more sensitivity.
1. Piezoelectric - These rugged and inexpensive sensors operate by a charge displacement during the strain in crystal lattices.

In general, ultrasonic sensors are the best choice for transparent targets. They can detect a sheet of transparent plastic film as easily as a wooden pallet.

Sensors: Sound

Sound

Microphones

Sound Sensor

A sensor for detecting sound is, in general, called a microphone. The microphone can be classified into several basic types including dynamic, electrostatic, and piezoelectric according to their conversion system.

The dynamic microphone still has big demands primarily in the music world, while the piezoelectric microphone is extensively used primarily for a microphone for low-frequency sound-level meters.

For measurement, electrostatic type (condenser) microphones are most popular because they can be downsized, have flat frequency responses over a wide frequency range, and provide markedly high stability as compared to other types of microphones.

The condenser microphones are available in two types: bias type and back electret type. The difference is whether the DC voltage is applied from the outside or permanently electrically polarized polymer film is used in place of applying voltage. In general, the bias type provides higher sensitivity and stability.

Sound Intensity Microphones

Sound intensity is a measure of the "flow of energy passing through a unit area per unit time" and its measurement unit is W/m2. The sound intensity microphone probe is designed to capture sound intensity together with the unit direction of flow as a vector quantity. This is achieved by incorporating more than one microphone in a probe to measure the sound energy flow. Conventional microphones can measure sound pressure (unit: Pa), which represents sound intensity at a specific place (one point), but can measure the direction of flow. The sound intensity microphone is therefore used for sound source probing and for measuring sound power.

Sensors: Temperature

Temperature

Typical applications for temperature sensors include:

- HVAC - room, duct, and refrigerant equipment
- Motors - overload protection
- Electronic circuits - semiconductor protection
- Electronic assemblies - thermal management, temperature compensation
- Process control - temperature regulation
- Automotive - air and oil temperature
- Appliances - heating and cooling temperature

Temperature Sensors

Sensor Types

1. **Thermocouples** - Thermocouples are pairs of dissimilar metal alloy wires joined at least at one end, which generate a net thermoelectric voltage between the two ends according to the size of the temperature difference between the ends, the relative Seebeck coefficient of the wire pair and the uniformity of the wire's relative Seebeck coefficient.
2. **Thermistors** - Thermistors (Resistance Thermometers) are instruments used to measure temperature by relating the change in resistance as a function of temperature.
3. **Radiation Pyrometer** - A device to measure temperature by sensing the thermal radiation emitted from the object.
4. **Radiation Thermometers (Optical Pyrometers and Infrared Thermometers)** - Optical Pyrometers are devices used to measure temperature of an object at high temperatures by sensing the brightness of an objects surface.
5. **Resistance Temperature Detectors (RTDs)** - RTD's (Resistance Temperature Detectors) are precision, wire-wound resistors with a known temperature resistance characteristic. In operation, the RTD is usually wired into a specific type of circuit (wheatstone bridge). They are nearly linear over a wide range of temperatures and can be made small enough to have response times of a fraction of a second. They require an electrical current to produce a voltage drop across the sensor that can be then measured by a calibrated read-out device. The output of this circuit can be used to drive a meter which has been calibrated in temperature, or to operate a relay to sound an alarm or shut down the motor. The Platinum RTD is the most accurate and stable temperature detector from zero to about 500°C. It can measure temperatures up to 800°C. The resistance of the RTD changes as a function of absolute temperature, so it is categorized as one of the absolute temperature devices. (In contrast, the thermocouple cannot measure absolute temperature; it can only measure relative temperature.)

6. **Fiber Optic Temperature Sensors** - Optical-based temperature sensors provide accurate and stable remote measurement of on-line temperatures in hazardous environments and in environments having high ambient electromagnetic fields without the need for calibration of individual probes and sensors.

   Optical temperature sensor systems measure temperatures from -200C to 600C safely and accurately even in extremely hazardous, corrosive, and high electro-magnetic field environments. They are ideal for use in these conditions because their glass-based technology is inherently immune to electrical interference and corrosion. Since there is no need to recalibrate individual sensors, operator and technician safety is greatly enhanced as the need for their repeated exposure to field conditions is eliminated.

   Probes are made from largely non-conducting and low thermal conductance material, resulting in high stability and low susceptibility to interference, and in increased operator safety. Optical cables also have a much higher information-carrying capacity and are far less subject to interference than electrical conductors.

7. **Silicon Temperature Sensors -** Integrated circuit temperature sensors differ significantly from the other types in a couple of important ways. The first is operating temperature range. A temperature sensor IC can operate over the nominal IC temperature range of -55 C to +150 C. Some devices go beyond this range while others, because of package or cost constraints, operate over a narrower range. The second difference is functionality. A silicon temperature sensor is an integrated circuit, including extennsive signal processing circuitry within the same package as the sensor.

Sensors: Velocity

Velocity

Linear Velocity Transducer - LVT

The LVT is based on the principle of magnetic induction and provide reliable velocity measurement in a linear motion. Passing a magnet through the coil form generates a voltage proportional to the magnets velocity and field strength. This output signal is used to carefully monitor component velocities in various applications.

Handheld Tachometer

Tachometer

The tachometer measures the angular velocity of a rotating shaft using one of two methods. The first type connects a DC generator (motor) to the shaft which produces a voltage proportional to the increase in shaft angular velocity. The second type utilizes a magnet with a pickup coil. As the magnet passes the coil a pulse is generated. The pulse magnitude and frequency are proportional to the angular speed.