

Transducers

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The ever increasing density of rail traffic has made it mandatory to enhance the pace of train operations. This has opened gates for modern signaling systems which involve the deployment of more intelligent machines and less man power.

Today signaling systems play a crucial role in ensuring fastest train operations with utmost safety standards. To achieve these prime objectives i.e., safety & efficiency, the signaling systems are being updated time and again.

1. Mechatronics is a multidisciplinary field of engineering which includes a wide variety of systems engineering, mechanical engineering, electrical engineering, telecommunications engineering, control engineering and computer engineering.

With the advent of modern signaling systems more and more number of microprocessor based equipments are inducted into Railway signaling installations. The efficient functioning of these systems depends on the availability of a reliable interface. They also need real time information of the field environment to access the latest changes in the field status and to take correct decision at the right moment.

A Measurement system is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system. A Measurement system comprises of sensors, transducers and signal processing devices. Today a wide variety of these elements and devices are available in the market. For a system designer it is essential to learn the principle of working of commonly used sensors/transducers in order to choose suitable transducers for the desired application

What is a Transducer?

A Transducer is a device which transforms a non-electrical physical quantity (i.e. temperature, sound or light) into an electrical signal (i.e. voltage,

current). It is basically a device which converts one form of energy to another.

When input is a physical quantity and output electrical it is known as Sensor

When input is electrical and output a physical quantity it is known as Actuator

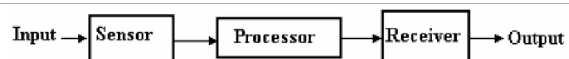
Examples of common transducers include the following:

• A microphone which converts sound into electrical impulses is a Sensor and a loudspeaker converts electrical impulses into sound is an Actuator

- A solar cell which converts light into electricity and a thermocouple converts thermal energy into electrical energy.
- An incandescent light bulb produces light by passing a current through a filament. Thus, a light bulb is a transducer for converting electrical energy into optical energy.
- An electric motor is a transducer for conversion of electricity into mechanical energy or motion.
- Antenna is the most basic transducer. It converts electromagnetic energy into electricity when it receives signals and does the opposite when it transmits
- Accelerometer converts the change in position of mass into an electrical signal. Accelerometers measure the force of acceleration and deceleration. They are used in automobiles, stability control, hard drives, and many electronic gadgets.

A sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical). Nowadays common sensors convert measurement of physical phenomena into an electrical signal.

A block diagram of a basic system consisting sensor is shown but they are usually more complex.



2. Signal range of Sensors:

Most of the modern analogue equipment works on the following standard signal ranges.

- Electric 4 to 20 mA
- Pneumatic 0.2 to 1.0 bar

Older electrical equipment use 0 to 10 V. Increasingly the instruments are digital with a binary digital encoder built in to give a binary digital output. Pneumatic signals are commonly used in process industries for safety especially when there is a risk of fire or explosion.

The advantage of having a standard range or using digital signals is that all equipment may be purchased ready calibrated. For analogue systems the minimum signal (Temperature, speed, force, pressure and so on) is represented by 4 mA or 0.2 bar and the maximum signal is represented by 20 mA or 1.0 bar.

Things that are commonly measured by using sensors are:

Temperature, Pressure, Speed, Flow rate, Force, Movement, Velocity and Acceleration

Stress and Strain, Level or Depth, Mass or Weight, Density, Size or Volume Acidity/Alkalinity

Sensor/transducers specifications:

Transducers are not perfect systems. Mechatronics design engineer must know the capability and shortcoming of a transducer or measurement system to properly assess its performance. There are a number of performance related parameters of a transducer. These parameters are called as sensor specifications.

Sensor specifications inform the user about the deviations from the ideal behaviour of the sensors. Following are the various specifications of a sensor/transducer system.

1. Range:

The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25-225 °C.

2. Span

The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

3. Error

Error is the difference between the result of

the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is -0.2 mm.

4. Accuracy

The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full-scale deflection. A piezoelectric transducer used to evaluate dynamic pressure phenomena associated with explosions, pulsations, or dynamic pressure conditions in motors, rocket engines, compressors, and other pressurized devices is capable to detect pressures between (0.7 KPa to 70 MPa). If it is specified with the accuracy of about $\pm 1\%$ full scale, then the reading given can be expected to be within ± 0.7 MPa.

5. Sensitivity

Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a sensitivity of $41 \mu\text{V}/^\circ\text{C}$.

6. Nonlinearity

The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Linearity is often specified in terms of percentage of nonlinearity, which is defined as:

$$\text{Nonlinearity (\%)} = \frac{\text{Maximum deviation in input}}{\text{Maximum full scale input}}$$

7. Hysteresis

The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. The hysteresis error value is normally specified as a positive or negative percentage of the specified input range.

8. Resolution

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full-scale reading or in absolute terms. For example, if a LVDT sensor measures a displacement up to

20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2 mm.

9. Stability

Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term 'drift' is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

10. Dead band/time

The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

11. Repeatability

It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

$$\text{Repeatability} = (\text{maximum} - \text{minimum values given}) \times 100 / \text{full range (2.1.2)}$$

12. Response time

Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

Classification of sensors

Sensors can be classified into various groups according to the factors such as measurand, application fields, conversion principle, energy domain of the measurand and thermodynamic considerations.

Application	Sensor/Transducer
Displacement, position and proximity sensors	<ul style="list-style-type: none"> • Potentiometer • Strain-gauged element • Capacitive element • Differential transformers • Eddy current proximity sensors • Inductive proximity switch • Optical encoders • Pneumatic sensors • Proximity switches (magnetic) • Hall effect sensors
Velocity and motion	<ul style="list-style-type: none"> • Incremental encoder • Tachogenerator • Pyroelectric sensors
Force	<ul style="list-style-type: none"> • Strain gauge load cell
Fluid pressure	<ul style="list-style-type: none"> • Diaphragm pressure gauge • Capsules, bellows, pressure tubes • Piezoelectric sensors • Tactile sensor

Liquid flow • Orifice plate	Turbine meter
Liquid level • Floats	Differential pressure
Temperature	Bimetallic strips <ul style="list-style-type: none"> • Resistance temperature detectors • Thermistors • Thermo-diodes and transistors • Thermocouples • Light sensors • Photo diodes • Photo resistors • Photo transistor

Classification of sensors basing on their applications is as shown in the table above.

Classification of sensors in view of their mode of operation:

Basing on their mode of operation, Sensors can be broadly classified in two categories: discrete event and continuous.

Discrete event, or on/off sensor, changes its state based on the occurrence of some external event. These sensors typically only give knowledge of two states based on the condition being sensed. They are based on mechanical, electrical or optical technology.

Continuous sensors provide information over the continuous range of operation of the process and are commonly used in continuous control applications, where the process is being regulated based on continuously sensed attribute data. They are based on electrical, optical and acoustical technologies.

Classification of sensors basing on power supply:

Basing on power supply the sensors can be classified as active and passive. A passive sensor has no power supply and all the energy it delivers to the next stage (the signal conditioning) is drawn from the measurand. Passive sensors are also known as self-generating sensors.

An active sensor is a modulator and can therefore deliver more energy to the next stage than it draws from the measurand. If the power supply is dc, the output is modulated by the measurand, and has the same frequency. If the supply is ac, the output is the carrier frequency with sidebands at signal frequency.

Some of the most commonly used sensors in Railway signaling systems are

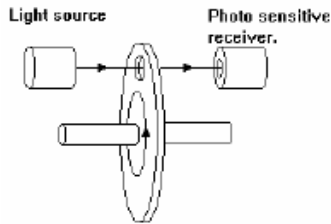
1) Wheel sensors in TPWS

- 2) Track side transducers in Axle counters
- 3) Temperature Sensor in Data logger and IPS
- 4) Input interface in EI systems and Data loggers
- 5) Optical sensors in LED signal units

1) Speed Transducers :

Speed transducers are widely used for measuring the output speed of a rotating object. There are many types using different principles and most of them produce an electrical output.

a) Optical types :

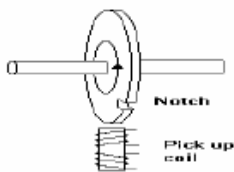


These use a light beam and a light sensitive cell. The beam is either reflected or interrupted so that pulses are produced for each revolution.

The pulses are then counted over a fixed time and the speed obtained. Electronic processing is required to time the pulses and turn the result into an analogue or digital signal. TPWS onboard system consists a wheel sensor which is of optical type.

b) Magnetic Pickups :

These use an inductive coil placed near to the rotating body. A small magnet on the body generates a pulse every time it passes the coil. If



the body is made of ferrous material, it will work without a magnet. A discontinuity in the surface such as a notch will cause a change in

the magnetic field and generate a pulse. The pulses must be processed to produce an analogue or digital output.

c) Tachometers :



There are two types, A.C. and D.C. The A.C. type generates a sinusoidal output. The frequency of the voltage

represents the speed of rotation. The frequency must be counted and processed. The D.C. type generates a voltage directly proportional to the speed. Both types must be coupled to the rotating

body. Very often the tachometer is built into electric motors to measure their speed. The tachometer is used in the on board equipment of AWS.

Optical fiber sensors:

Fiber-optic sensor devices have many applications in diverse technological fields, including the medical, chemical, and telecommunication industries. Optical fiber sensors have been developed to measure a wide variety of physical properties, such as chemical changes, strain, electric and magnetic fields, temperature, pressure, rotation, displacement (position), radiation, flow, liquid level, vibrations, light intensity, and color.

Fiber-optic sensors are devices that can perform in harsh environments where conventional electrical and electronic sensors have difficulties. In comparison with the other types of sensors, optical fiber sensors exhibit a number of advantages; they

- Are non-electrical devices
- Require small cable sizes and weights
- Enable small sensor sizes
- Allow access into normally inaccessible areas
- Often do not require contact
- Permit remote sensing
- Offer immunity to radio frequency interference (RFI) and electromagnetic interference (EMI)
- Do not contaminate their surroundings and are not subject to corrosion
- Provide high sensitivity, resolution and dynamic range
- Offer sensitivity to multiple environmental parameters
- Can be interfaced with data communication systems

Optical fiber sensors are dielectric devices that are generally chemically inert. They do not require electric cables for their performance and are technically ideal for working in hostile media or corrosive environments for applications in remote sensing.

The basic components of an optical fiber sensor are an optical source, a transducer, and a receiver. Lasers, diodes, and/or LEDs are often used as the optical source in these sensing devices. An optical fiber (single or multimode),

doped fibers, and/or bulk materials are employed as the transducer (sensor heart).

At the output of the sensor system, a photodetector is used to detect the variation in the optical signal that is caused by the physical perturbation of the system. In the optical fiber sensors systems, the optical parameters that can be modulated are the amplitude, phase, color (spectral signal), and state of polarization.

Optical sensors are provided in LED Signal units to sense the intensity of light emitted by the LEDs. The output from optical sensors is given to the current regulator unit for corrective / alarm action.

Input interfacing sensors:

For an electronic or micro-electronic circuit to be useful and effective, it has to interface with something. Input interface circuits connect electronic circuits such as op-amps, logic gates, etc. to the outside world expanding its capabilities.

Electronic circuits amplify, buffer or process the signals received from sensors to store as input information or to control lamps, relays or actuators for output control. Either way, input interfacing circuits convert the voltage and current output of one circuit to the equivalent of another.

Input sensors provide input information about an environment. Physical quantities such as temperature, pressure or position that vary slowly or continuously with time can be measured using various sensors giving an output signal relative to the physical quantity being measured.

Many of the sensors that we use in electronic circuits and projects are resistive i.e., their resistance changes with the measured quantity. For example, thermistors, strain gauges or light dependant resistors (LDR). These devices are all classed as input devices.

Interfacing with Opto Devices :

An Optocoupler (or optoisolator) is an electronic component with an LED and photo-sensitive device, such as a photodiode or phototransistor encased in the same package. The Opto-coupler interconnects two separate electrical circuits by means of a light sensitive optical interface. This means that we can effectively interface two circuits of different voltage or power ratings together without one electrically affecting the other.

Optical Switches (or opto-switches) are another type of photo switching devices which can be used for input interfacing. An optical switch can be used for interfacing harmful voltage levels onto the input pins of microcontrollers and other such digital circuits or for detecting objects using light, providing a high degree of isolation (typically 2-5kV).

Optical switches come in a variety of different types and designs for use in a whole range of interfacing applications. The most common use for opto-switches is in the detection of moving or stationary objects. The phototransistor and photodarlington configurations provide most of the features required for photo-switches and are therefore the most commonly used

Today with modern PC's, microcontrollers, and other such microprocessor based systems, input interfacing circuits allows these low voltage, low power devices to easily communicate with the outside world as many of these PC based devices have built-in input-output ports for transferring data to and from the controllers program and attached switches or sensors.

We have seen that sensors are electrical components that convert one type of property into an electrical signal thereby functioning as input devices. Adding input sensors to an electronic circuit can expand its capabilities by providing information about the surrounding environment. However, sensors can not operate on their own and in the most cases an electrical or electronic circuit called an interface is required.

Then input interfacing circuits allow external devices to exchange signals (data or codes) from either simple switches using switch debouncing techniques from a single push button or keyboard for data entry, to input sensors that can detect physical quantities such as light, temperature, pressure, and speed for conversion using analogue-to-digital converters. Then interfacing circuits allow us to do just that.

The field and panel inputs to the microprocessors in a EI system are connected through I/O Interface cards. The I/O cards consists of opto couplers which are optical sensors to sense the status of relays, buttons and keys etc