Sensors and Transducers (EI401)

Introduction

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Course Outcome

At the end of this course, the learner will be able to:

- **EI401.1 State the fundamental principles of various types of sensors and Transducers i.e. Mechanical, Electromechanical, Resistive, Inductive, Capacitive, Piezoelectric, Thermal, Magneticetc.**
- **EI401.2 Explain the working principle of various types of sensors and transducers**
- **EI401.3 Choose a suitable sensor/transducer for a particular industrial application**
- **EI401.4 Differentiate various sensors/transducers based on their utility for a particular application**
- **EI401.5 Evaluate the output of a sensor/transducer for a particular industrial system**
- **EI401.6 Design simple sensing/transduction system for a small industrial application**

Prerequisite:

To understand this course, the learner must have idea of elementary physics, Basic Electrical Engineering and Calculus.

RecommendedReading:

- **TextBooks:**

1.D.C.Patranabis, Sensors and Transducers,PHI,2nd ed.

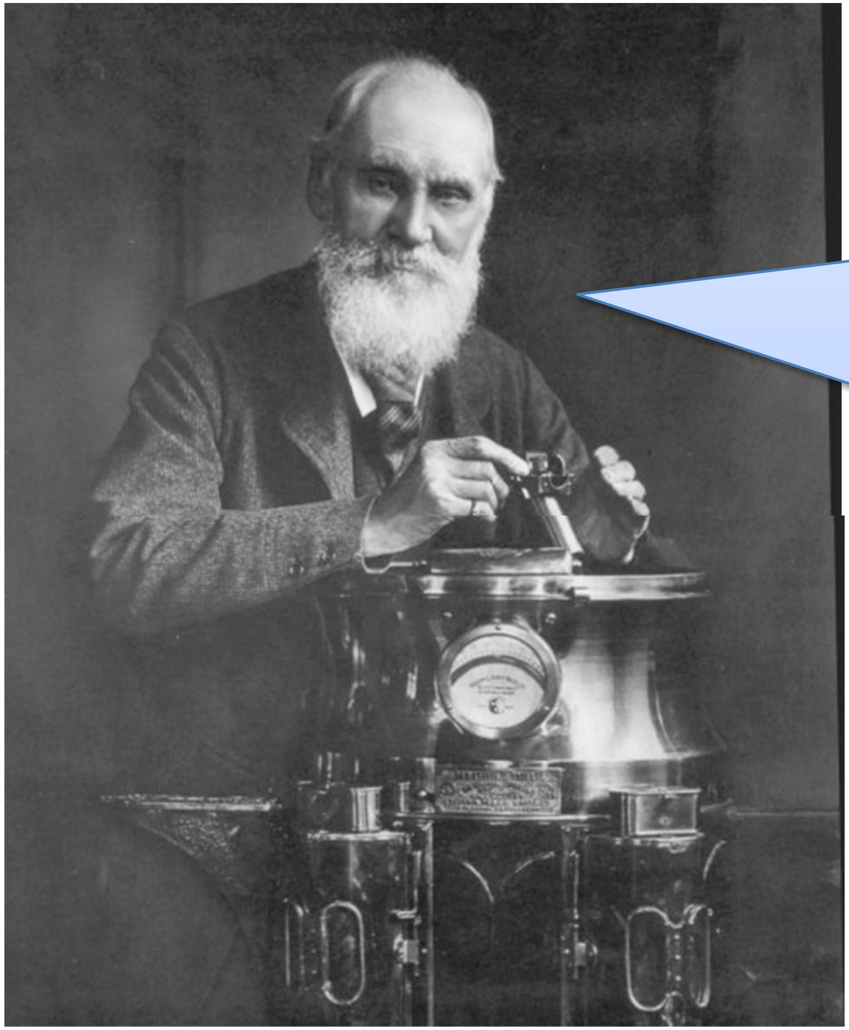
2.E.A.Doebelin, Measurement Systems: Application and Design, McGrawHill, NewYork

3.H.K.P.Neubert, Instrument Transducers, Oxford University Press, London and Calcutta

- **ReferenceBooks:**

1. D.V.S.Murty, Transducers and Instrumentation, PHI, 2nd ed.
2. K. Krishnaswamy and S.Vijayachitra, Industrial Instrumentation, New Age International Publishers, 2nd ed.
3. B.G.Liptak, Instrument Engineers‘ Handbook-Process Measurement and Analysis, Vol.1, 4th Edition, CRC Press.

You cannot control what you cannot measure



"When you can measure what you are speaking about, and express it in numbers, you know something about it. When you cannot measure it, when you cannot express it in numbers, your knowledge is of unsatisfactory kind"

Lord Kelvin (1824-1907)

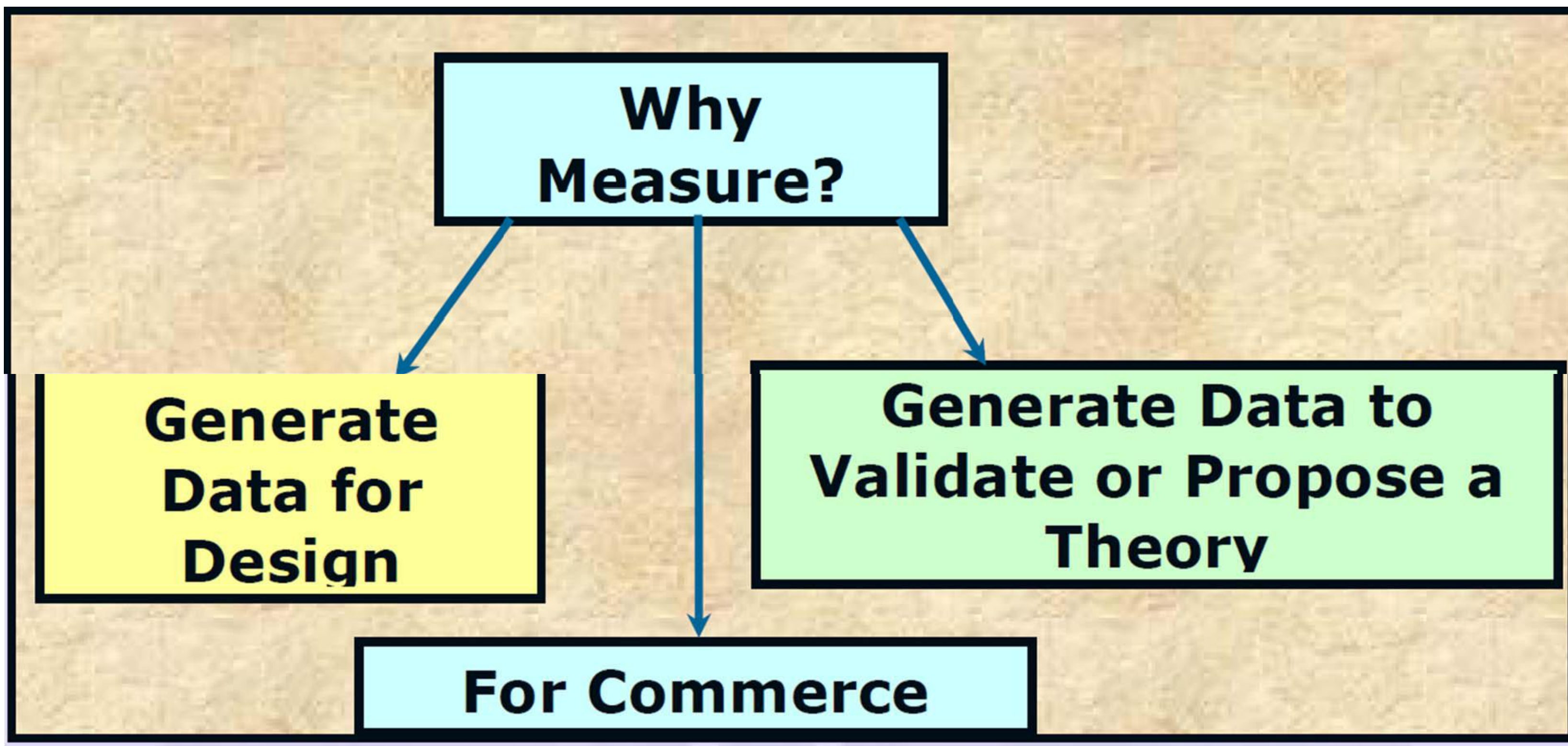
Introduction

•Human endeavor is a direct outcome of man's curiosity to learn and understand the environment in which he lives.

• All the successful achievements in science and technology are entirely due to his ability to measure the state, condition, or characteristics of the physical systems in quantitative terms
with sufficient accuracy.

Why measure?

- We recognize three reasons for making measurements as indicated in Figure.
- From the point of view of the course measurements for commerce is outside its scope.



Generate data for design

- Engineers design physical systems in the form of machines to

serve some specified functions.

- The behavior of the parts of the machine during the operation

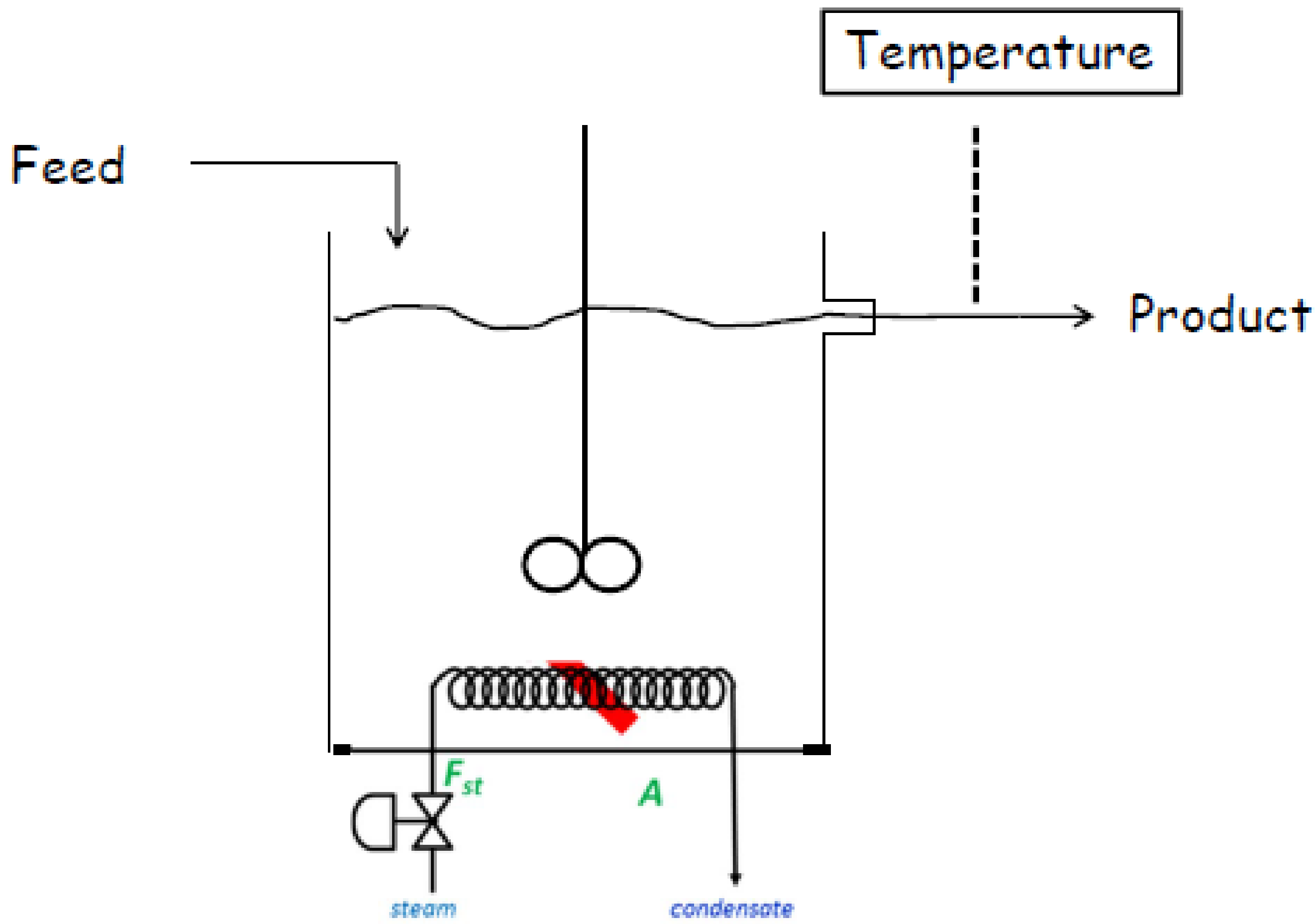
of the machine needs to be examined or analyzed or designed such that it functions reliably.

- Such an activity needs data regarding the machine parts in terms of material properties.
- These are obtained by performing measurements in the laboratory.

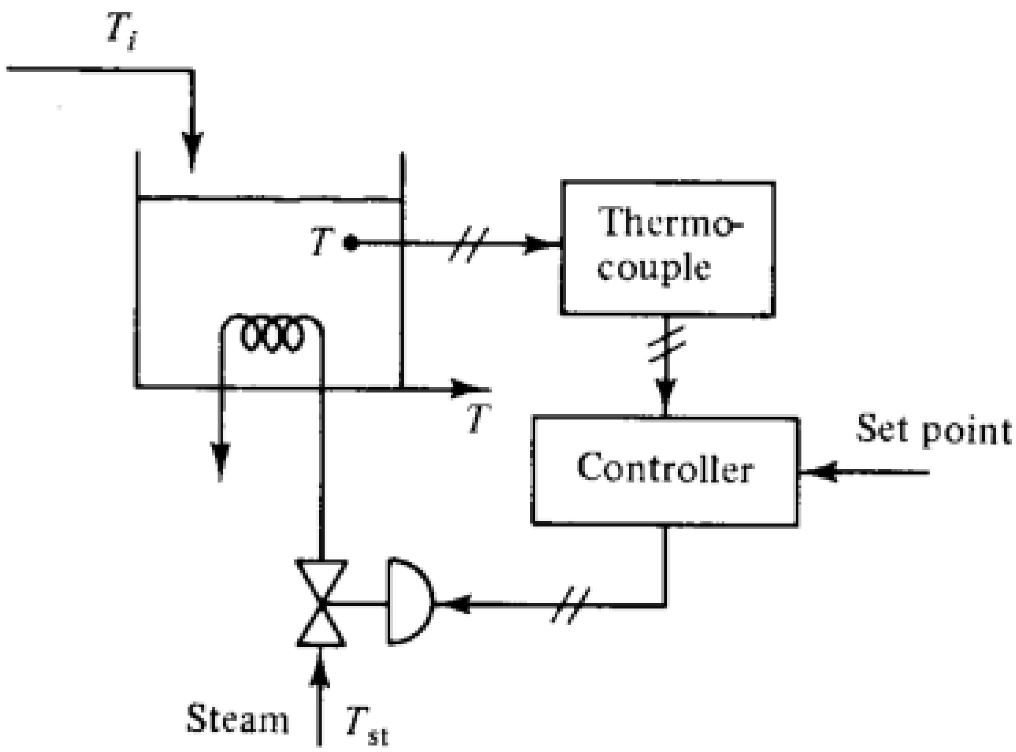
Generate data to validate a theory

- The **scientific method** consists in the study of nature to understand the way it works.
- Science proposes hypotheses or theories based on observations and need to be validated with carefully performed experiments that use many measurements.
- When once a theory has been established it may be used to make predictions which may themselves be confirmed by further experiments.

Example: Control of Stirred Tank Heater



Example: Closed-Loop temperature control



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Measurement for industry

- From the above example, for any industry, measurement application can be classified into three major categories

❑ Monitoring of processes and operations

❑ Control of processes and operations

❑ Experimental engineering analysis

Functional elements of an instrument

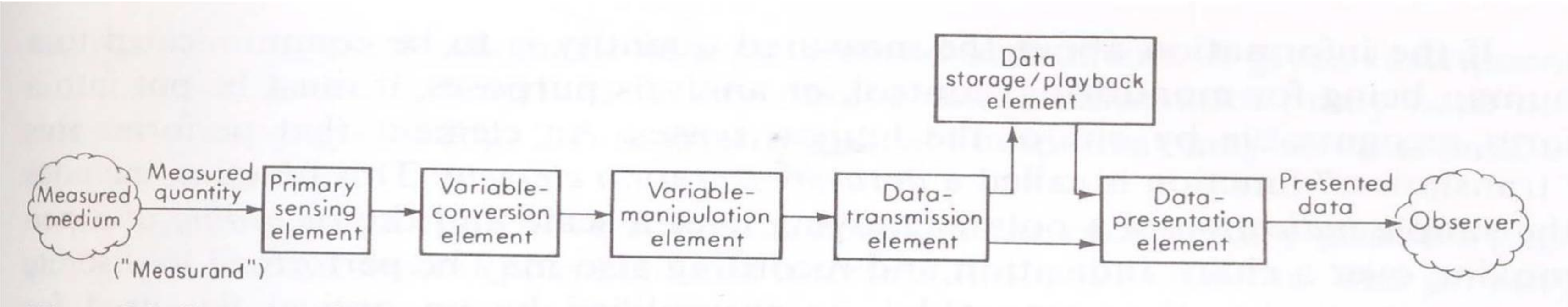


Figure represents a possible arrangement of functional elements in an instrument and includes all the basic functions considered necessary for a description of any instrument.

- The **primary sensing element is that which first receives energy from** the measured medium and produces an output depending in some way on the measured quantity.
- The output signal of the primary sensing element is some physical variable, such as displacement or voltage.
- For the instrument to perform the desired function, it may be necessary to convert this variable to another more suitable variable while preserving the information content of the original signal.

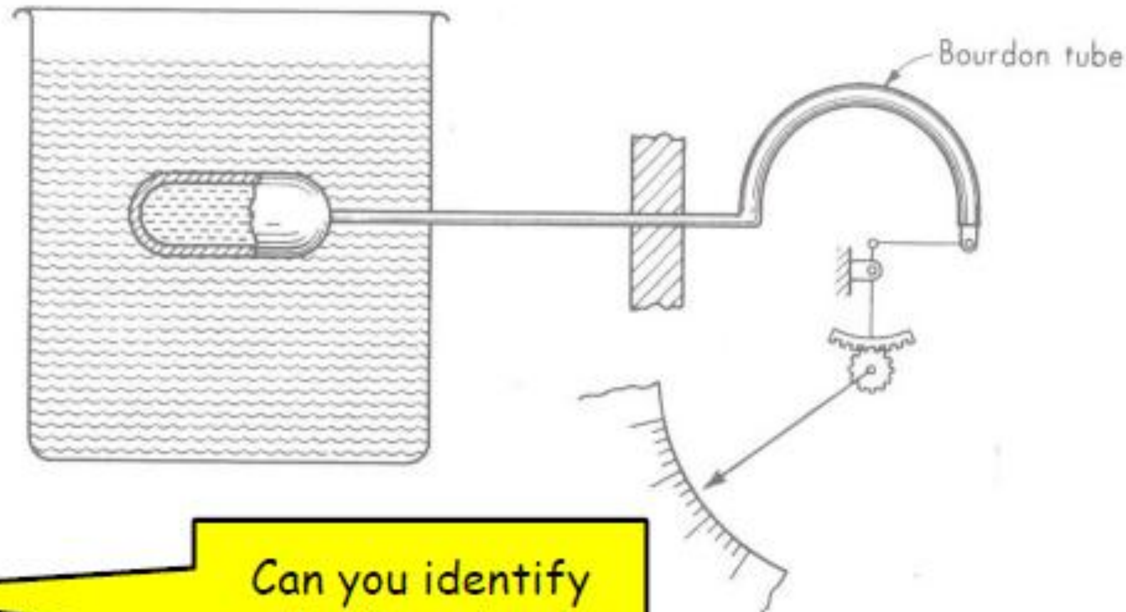
Contd.

- An element that performs such a function is called as **variable conversion element.**
- In performing its intended task, an instrument may require that a signal represented by some physical variable be manipulated in some way.
- By “manipulation” means specifically a change in numerical value according to some definite rule but a preservation of the physical nature of the variable.
- Example: Electronic Amplifier
- An element that performs such a function is called a **variable manipulation element.**
- When the functional element of an instrument are actually physically separated, it becomes necessary to transmit the data from one to another. An element performing this function is called a **data transmission element.**

Contd.

- If the information about the measured quantity is to be communicated to a human being for monitoring, control or analysis purposes, it must be put into a form recognizable by one of the human senses.
- An element that performs the “translation” function is called a **data representation element.**
- Although data storage in the form of pen/ink recording is often employed, some applications require a distinct **data storage/ playback function which can easily re-create the stored data** upon command.

Pressure type Thermometer



Can you identify the functional elements of this measuring system?

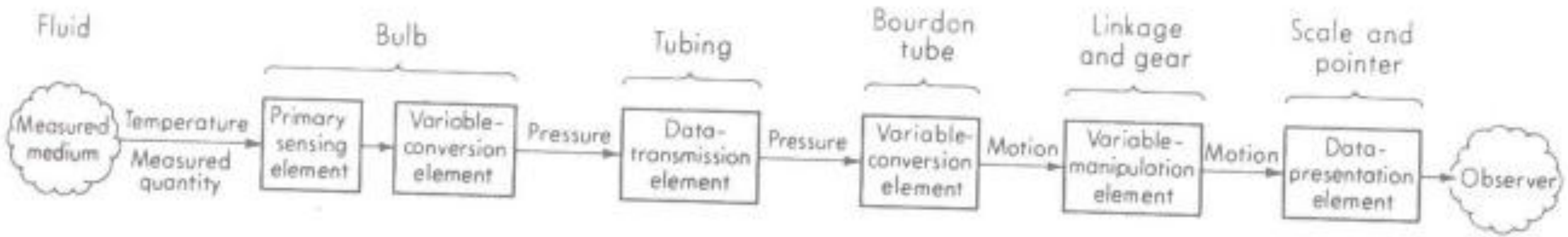


Figure 2.3 Pressure thermometer.

- Figure depicts a pressure-type thermometer.
- The liquid-filled bulb acts as a **primary sensor and variable-conversion element since a temperature change results in a pressure buildup within the** bulb, because of the constrained thermal expansion of the filling fluid.
- This pressure is **transmitted through the tube to a Bourdon type pressure** gauge, which converts pressure to displacement.
- This displacement is **manipulated by the linkage and gearing to give a larger** pointer motion.
- A scale and pointer again serve for **data presentation.**

Definitions - Sensors

- Also called: transducer, probe, gauge, detector, pick-up etc.
- Start with the dictionary:
- A device that responds to a physical stimulus and transmits a resulting impulse. (New Collegiate Dictionary)
- A device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control) . (Webster, 3rd ed., 1999)

Definitions - Transducers

- A device that is actuated by power from one system and supplies power usually in another form to a second system. (New Collegiate Dictionary)

- A substance or device, such as a piezoelectric crystal, that converts input energy of one form into output energy of another. (from: Trans-ducere – to transfer, to lead) (American Heritage Dictionary, 3rd ed., 1996)

- A device that is actuated by power from one system and supplies power usually in another form to a second system (a loudspeaker is a transducer that transforms electrical signals to sound energy) . (Webster, 3rd ed., 1999)

Definitions - Actuator

- A mechanism for moving or controlling something indirectly instead of by hand. (New Collegiate Dictionary)

- One that actuates; a mechanical device for moving or controlling something. (Webster, 3rd ed., 1999)

More confusion

Transducer can mean:

- sensor
- actuator

  transducer can be part of a sensor

  sensor can be part of a transducer

- Many sensors can work as actuators (duality)
- Many actuators can work as sensors
- *What is it then? - All of the above!*

Our definitions

Sensor

- A device that responds to a physical stimulus.

Transducer

- A device that converts energy of one form into energy of another form.

Actuator

- A device or mechanism capable of performing a physical action

Stimulus

- The quantity that is sensed.
- Sometimes called the measurand.

Classification of Sensors

- Sensor classification schemes range from very simple to the complex. Depending on the classification purpose, different classification criteria may be selected.

- ❑ On the basis of Detection Means Used in Sensors
- ❑ As passive and active transducer
- ❑ As analog and digital transducer
- ❑ As Contact and non-contact sensors
- ❑ As Absolute and relative sensors
- ❑ As transducer and inverse transducer
- ❑ On the basis of Conversion Phenomena
- ❑ On the basis of Field of Application
- ❑ On the basis of specifications

Classification based upon principle of Transduction

- A transducer provides a usable output in response to a specific input measured which may be physical or mechanical quantity, property or condition.
- The responding device may be mechanical, electrical, magnetic, optical, chemical, acoustic, thermal, nuclear or a combination of any two or more.

- **Classification by broad area of detection**

- Electric sensors
- Magnetic
- Electromagnetic
- Acoustic
- Chemical
- Optical
- Heat, Temperature
- Mechanical
- Radiation
- Biological
- Etc.

Mechanical Transducer

- **Mechanical transduces are the mechanical elements that are** used for converting one form of energy to other form generally displacement.
- Mechanical transducers possess high accuracy, ruggedness, relatively low cost and operate without any external power supplies.
- But such types are not advantageous for many of the modern scientific experiments and process control instrumentation because of their poor frequency response, requirement of large forces to overcome mechanical friction, incompatibility when remote control or indication required.
- All these drawbacks have been overcome with the introduction of electrical transducer.

Electrical Transducer

An **electrical transducer is a sensing device by which a physical,** mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical voltage or current proportional to the input measured.

- The main advantages of an electrical transducer may be summarized as follows:

- The electrical output can be amplified to any desired level.
- The output can be indicated and recorded remotely at a distance from the sensing medium.

Active and passive Transducer

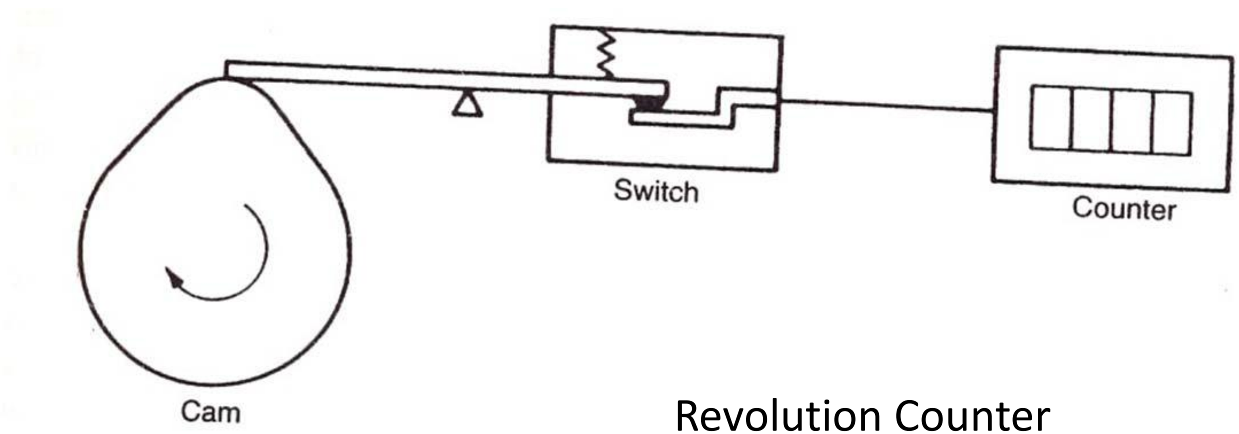
- **Passive transducers (sometimes called self-generating** transducers) depend on their power transfer characteristics for operation and do not need an external power source. Some examples are electromagnetic, thermoelectric, radioactive, piezoelectric, and photovoltaic transducer.
- **External power is required to operate active sensor/transducer, and they do not depend on their own power** conversion characteristics for operation.
- A good example for an active device is a resistive transducer, such a potentiometer, which depends on its power dissipation through a resistor to generate the output signal.

Contd.

- Note that an active transducers requires a separate power source (power supply) for operation, whereas a passive transducer draws power from a measured signal (measurand).
- Since passive transducers derive their energy almost entirely from measurand, they generally tend to distort (or load) the measured signal to a greater extent than an active transducer.
- Precautions can be taken to reduce such loading effects.
- On the other hand, passive transduce are generally simple design, more reliable, and less costly.

Analog and Digital Transducer

- An **analog transducer gives an output which varies continuously** as the quantity being measured changes. The output can have an infinite number of values within the range that the transducer is designed to measure.
- Example: Deflection type pressure gauge
- A **digital transducer has an output which varies in discrete** steps and so can only have a finite number of values.
- Example: Rev Counter



Revolution Counter

Contact and non-contact sensors

- **Contact sensor: a sensor that requires physical contact** with the stimulus.
- Examples: strain gauges, most temperature sensors
- **Non-contact sensor: requires no physical contact.**
- Examples: most optical and magnetic sensors,

infrared thermometers, etc.

Absolute and relative sensors

- Absolute sensor: a sensor that reacts to a stimulus on an absolute scale: Thermistors, strain gauges, etc., (thermistor will always read the absolute temperature).

- Relative scale: The stimulus is sensed relative to a fixed or variable reference. Thermocouple measures the temperature difference, pressure is often measured relative to atmospheric pressure.

Transducer & Inverse Transducer

Transducer: A transducer can be defined as a device which converts one form of energy to other generally in electrical quantity.

Inverse Transducer: An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity.

Example: A piezoelectric transducer

Conversion Phenomena

Classification by physical law

- Photoelectric
- Magnetoelectric
- Thermoelectric
- Photoconductive
- Magnitostrictive
- Electrostrictive
- Photomagnetic
- Thermoelastic
- Thermomagnetic
- Thermooptic
- Electrochermical
- Magnetoresistive
- Photoelastic
- Etc.

Field of Application

Classification by area of application

- Consumer products
- Military applications
- Infrastructure
- Energy
- Heat
- Manufacturing
- Transportation
- Automotive
- Avionic
- Marine
- Space
- Scientific
- Etc.

Classification by specifications

Classification by specifications

- Accuracy
- Sensitivity
- Stability
- Response time
- Hysteresis
- Frequency response
- Input (stimulus) range
- Resolution
- Linearity
- Hardness (to environmental conditions, etc.)
- Cost
- Size, weight,
- Construction materials
- Operating temperature
- Etc.