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F.Y.BSc (Computer Science)

Semester-II

Electronics Paper-I

Subject- ELC-121 – Instrumentation Systems

According to new CBCS syllabus w.e.f.2019-2020

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Unit-I- Introduction to Instrumentation System

- Black Diagram of Instrumentation System, Definition of sensor, Transducer and actuators.
- Classification of Sensor - Active and passive Sensor.
- Specification of sensor – Accuracy, range, Linearity, Sensitivity, Resolution, Reproducibility.

Introduction:

An instrumentation deals with the instruments designed either for measurement control of one or many parameters such as physical (length, weight, temperature etc.), chemical (pH, electrical conductivity, hardness etc.), electrical (voltage, current, power etc), environmental (humidity, temperature, etc.) and so on.

The Measurement:

The measurement is the natural process a human being uses in understanding the world around it. One compares the size of one object with the other to know bigness or smallness of the object. The size of room, furniture, utensils, trees, mountains and sky is judged by a person observation and comparison.

Thus comparison with the predefined standards is the measurement.

In early days the measurement was restricted to fundamental quantities like length, mass and time and derived quantities like area, volume, velocity, speed, weight, pressure etc.

Later extended to almost all the physical quantities like temperature, humidity, brightness, power, energy, electromagnetic wave radiation etc.

The Instrument:

The limited ability of human being can be extended by using external physical devices (Tools, aids) known as instruments.

The instruments can increase accuracy, precision and reliability of measurement, can extend the area of measurement which is otherwise inaccessible to human being.

Example: measurements in hazardous conditions, at a distance, underwater etc.

The measured values of the quantities may further help in taking appropriate actions and decisions.

The Instrumentation:

Art and science of using instruments for measurement or control is known as instrumentation.

Examples: i) meter board of a car or motorcycle (it contains meters to indicate distance travelled, speed, condition of oil, fuel level, cooling water, charge of battery etc)

ii) control board of aircraft, in satellite control stations or in the control cabin of an automated process industry.

Instrumentation System:

The instrumentation system is designed for two purposes:

1. Measurement of parameters
2. Control of parameters

Measurement System:

A monitoring or measurement system is a combination of different physical devices used to measure certain quantity or parameter. Figure shows the blocks of the system.

The plant represents the process that is being monitored.

The process may have one or more parameters to be measured. These parameters are known as measurands.

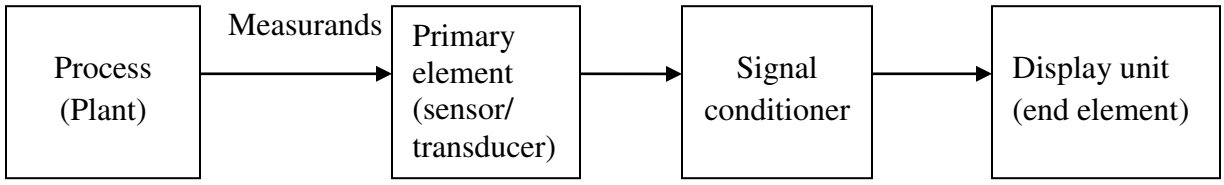


Figure: Block diagram of Measurement system

The measurement system consists of three distinct blocks. These are:

i. **Primary element (sensor/transducer):** These are the devices which are directly in contact with the process and sense or pick up process parameter value.

ii. **Signal conditioner:** The output available from the sensor may not be suitable for further use. It is necessary to modify it to suit the requirements of display unit. Examples: Amplifiers, filters, current to voltage converters, ADC and DAC. In case, if the output of the sensor is suitable for display unit, this stage is absent.

iii. **The Display unit (End Element):** The end device gives the required information about measured quantity in the user - friendly form. The display may be in the form of indicators, audio, visual display or in recorded form. Accordingly display can be analog meters, digital meters (LED or LCD), recorders, plotters, storage devices etc.

Control System:

A control system can be defined as a combination of physical devices used to control one or more parameters of the plant or process.

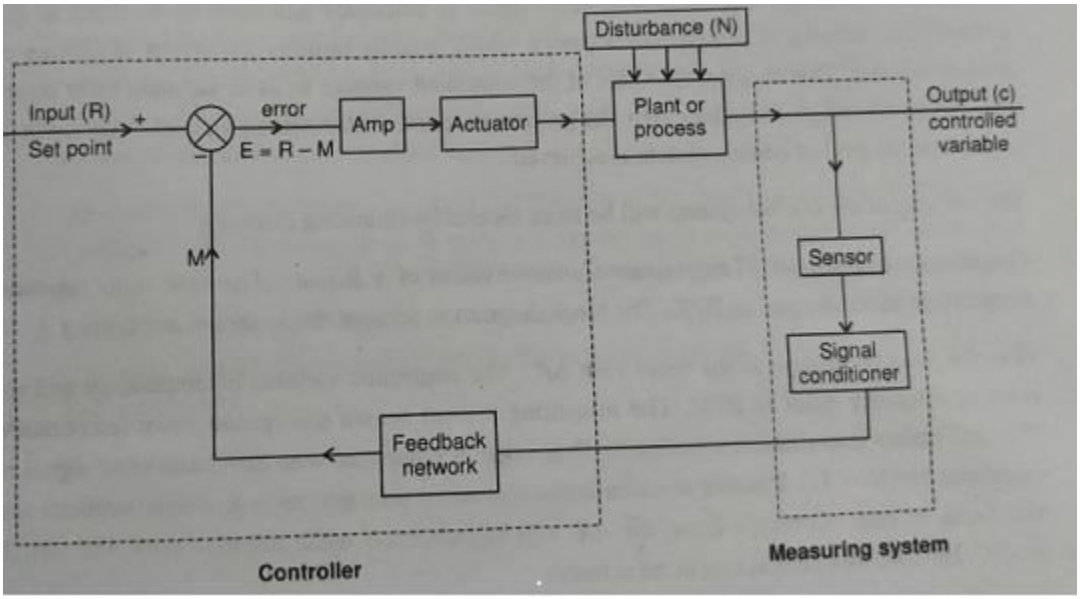


Figure shows typical control system. The major blocks of the control system are:

i. The plant or process under control
ii. The measuring system and
iii. The controller

The plant or process under control: The plant is that part of the system or process which is being controlled. It is a complex system and its characteristic behavior can be controlled by controlling certain parameters. The parameters are called output variables or controlled variables. To get desired performance of plant, the set of predetermined values of parameters are needed. These are called reference variables/set points.

The measuring system: The measuring system measures the actual value of controlled variable using sensor and signal conditioners. These values then form the inputs of the controller.
The controller has two inputs: one received from measuring system (M) and another set point (R).

The controller: The controller compares the measured value with the desired value. The algebraic difference between two generates error (E). The error signal is amplified and used as an input to the actuator. The actuator is a high power device which actually initiates the action of change of process variable. This changes the value of the controlled variable so as to maintain error signal zero. When error signal becomes zero, the process parameter value becomes equal to set value. It means that the goal of control system is achieved.

Examples:

1. The control of temperature of oven, iron, refrigerator or room is one such example in which, the temperature is sensed by the sensors and power supply is switched on or off to control the temperature.
2. The water - level controller for overhead tank is another example, where in water level is sensed and pump is switched on or off to maintain level within certain limits.
3. The washing machine, remote control of TV and VCR are yet another example.
4. More sophisticated control systems can be witnessed in process control, in robotics, in aircrafts, in combat weapons, in guided missiles, in satellite - control stations, in space research etc.

Types of control System:

1. Closed loop control system:

The control system which forms a closed loop through feedback path and hence known as closed loop system or feedback system.

The feedback type control system provides continuous vigilance over the value of controlled variable.

The temperature of room may get affected due to change in outside temperature, opening of doors, windows or any other such disturbances. The closed loop system will

automatically account for such changes and hence is also known as automatic control system. It increases accuracy of the control.

2. Open loop control system:

In certain applications, the feedback path is absent, or is assigned to human being. Such a system is known as open loop control system.

Example: remote control of TV is open loop system. It is the operator who gives feedback if volume is to be increased or decreased. Such systems have limited accuracy, especially in case of outside disturbance.

However, such systems are simple, less costly and fast in operation.

In majority of industrial applications closed loop control systems are used because of their better dynamic performance, accuracy and adaptability to disturbance.

Sensor, Transducers and Actuators:

Sensors:

It is the first element of process control system. Sensor is the device which senses the value of the process variable (measurand). A wide variety of parameters are there to be measured. Typical process variables are temperature, pressure, flow rate, humidity, speed, tilt etc.

Sensor should give faithful information regarding the process variable, without any distortion. Accuracy of the control system cannot be achieved unless the variable is measurand by the sensor with a high degree of accuracy.

Transducers:

Transducer is a device which converts signal from one form to another form for indication, recording or control.

The device used for conversion of a non-electrical quantity into an electrical signal is a transducer. Transduction means conversion of input information into suitable form for output.

Example: A properly cut piezoelectric crystal can be called a sensor whereas it becomes a transducer with appropriate electrodes and input/output mechanisms attached to it.

Another example is that a glass thermometer is a sensor as it displays value of temperature in form of displacement of mercury.

While RTD is a transducer as it converts temperature into resistance change.

"All sensors are transducers but all transducers may not be sensors. Transducers are treated as sensors if they do the measurement of the variable".

Actuators:

Controller generates output by comparing reference point and actual process variable. This output when given to an actuator, actuates or operates a mechanism that changes the process value. The operation of actuator involves the steps necessary to convert the control signal in the form required by the final control element.

Example: In A/C room, the temperature of the room can be varied by switching ON or OFF the cooler. Here, to switch ON or OFF the cooler, switch is required. It is called as 'actuator'.

In water - control or pressure control system, to increase or decrease water flow, a valve (fins control element) is to be operated. The device that converts the control signal into physical action of opening or closing the valve is actuator.

Depending on the operating mechanism the actuators are broadly classified as:

i. **Electrical:** Translates a control signal into an electrical signal.
ii. **Pneumatic:** Translates a control signal into a large force or torque.
iii. **Hydraulic:** Used when very large force is required. It uses an incompressible fluid to provide the high pressure.

Classification of Sensors, Active and Passive Sensors:

As selection of sensor plays a vital role in efficiency and accuracy of Instrumentation system designer must select sensor very carefully. Broad classification of sensors is as given below:

1. The process variable/measurand they measure
2. Basic phenomenon on which they work (Principal of transduction).
3. Energy Requirement (Passive or Active transducers)

Classification based on the Measurand:

There are many types of variables required to be measured/controlled. Depending on the process variable or measurand one has different types of sensors. e.g., RTD, thermostat, bimetallic strip are some sensors used for sensing temperature while Bourdan tube, bellows, diaphragm are pressure sensors, and so on.

Classification Based upon the Principle of Transduction:

Due to change in process variable, dimension, resistance, inductance or capacitance of the material may change.

Depending on the change one has resistive, inductive or capacitive type of sensors e.g. in thermistors - resistance of the semiconductor material changes with the temperature. In capacitor microphone, the capacitance of microphone varies with the sound pressure and so on.

Active and Passive Sensor:

Active sensors: They are self-powering devices and do not require an external power supply or excitation for sensing and converting one form of signal into another form. These sensors include thermoelectric, piezoelectric, photovoltaic, electromagnetic, electrodynamic, magneto strictive, electrokinetic, pyroelectric and galvanic sensors. In case of piezoelectric crystal, when force is applied across the crystal, an output voltage is produced. Photovoltaic devices produce voltage when illuminated by light. In both these sensors, power supply is not needed for their working.

Passive sensors: Passive sensors operate under energy controlling principles. These are not self-generating type and require an external power supply for sensing and for conversion of one form of signal to another form of signal.

Typical examples of passive transducers are resistive, inductive and capacitive sensors. Any change in these three primary parameters can be recognized only when the element is made 'live' by electric excitation: otherwise, they are in dead state. In the absence of external power, the sensor cannot work and hence is called as passive sensor.

Example: in piezoresistive sensors the resistance of the crystal changes by the application of pressure.

In photoconductive devices conductivity of the material changes with illumination.

Characteristics of Transducers:

The important characteristics of transducers are as follows:

1. **Range:** The range conveys the information about the lower and upper limit values of the measurand.

   The range of a sensor is defined as the difference between the largest and the smallest reading of the measurand.

   Suppose the highest value of measurand which can be measured satisfactorily is X_{max} units and the minimum value for the same is X_{min}, then the sensor range is X_{min} to X_{max}.

2. **Error:** The algebraic difference between the measured value (M) and actual or true value (T) of a measurand is defined as error (E). Thus

   E = M-T

   Error can be negative or positive depending upon the relative magnitudes of M and T.

   The error therefore represents the actual value of the measurand, predicted from the measurement.

3. **Accuracy:** It is defined as the closeness with which the reading approaches an accepted standard value or true value. Percentage accuracy is specified as the percentage deviation or inaccuracy of the measurement from the true value and is a ratio of the error of indicated value to the true value, expressed as a percentage.

   % Inaccuracy = Error /True value x 100

4. **Precision:** It is a measure of the reproducibility of the measurements. Precision is defined as the closeness with which individual measurements are distributed about their mean value. If the same measurement is done several times, the output value should be the same for all. But in practice readings will be clustered around the mean value in a random manner. The more the number of readings falling very close to the value, the more precise the instrument is.

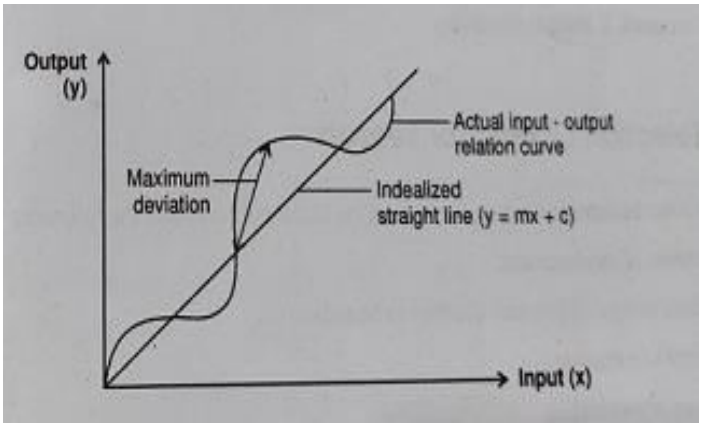
   High precision does not indicate high degree of accuracy.

5. **Linearity:** One of the important characteristics of sensor is linearity i.e. the output should be linearly proportional to the input. Most of the systems require a linear behaviour as it simplifies the design and analysis of whole system.

   Linear input - output relation can be written as y = mx + c, where y is the output, x is the input m is the slope and c is the intercept (constant).

   The linearity is generally expressed as a percentage of the deviation of any point from the idealized straight line as shown in figure. The non-linearity is given by

   % Nonlinearity = (Maximum deviation of output from the idealized straight line) / actual reading X100



6. **Resolution:** Resolution is defined as the smallest incremental change in the input that would produce a detectable change in the output. If the input is increased very slowly from some arbitrary (non-zero) input value, it is found that output does not change till certain increment in input is exceeded. This increment is nothing but resolution. In short it is the smallest measurable input change.

   Resolution is often expressed as percentage of the measured range.

   For a detectable output Δ y, if the minimum change in input is $(\Delta x)_{min}$, then the maximum resolution is

   $R_{max}(\%) = 100\ (\Delta x)_{min}$ / Range

7. **Reproducibility:** Reproducibility is the ability of sensor to produce output readings when the same input is applied at different times under different conditions and by different instruments. It indicates same characteristic behavior of the sensor under different environmental conditions, guaranteeing accuracy even under external disturbance or changed conditions.

8. **Sensitivity:** Sensitivity is defined as the ratio of the changes in the output of a sensor to a change in a value of the measurand. It is given by

   $S = \Delta y / \Delta x$

   If sensitivity changes with time and temperature or any other parameter, drift is said to be occurred. It leads to instability.

Selection Criteria for Sensors

To choose the transducer for specific application one should consider the following points:

1. Purpose of measurement.
2. Nature or type of physical quantity to be measured.
3. Source of measurand.
4. Range of measurand.
5. Order of accuracy and precision required in the measurement.
6. Ambient conditions.
7. Life span of sensor.
8. Transduction principle.
9. Availability of sensor.
10. Ease of operation.
11. Cost.