2.16 PROXIMITY SENSORS

A ***proximity sensor*** consists of an *element that changes either its state or an analog signal when it is close to, but often not actually touching, an object.*

Magnetic, electrical capacitance, inductance, and eddy current methods are particularly suited to the design of a proximity sensor.

- A ***photoemitter-detector pairs*** represents another approach, where *interruption or reflection of a beam of light is used to detect an object in a non-contact manner*. The emitter and détecter are usually a phototransistor and a photodiode.

Common ***applications*** for proximity sensors and limit switches include :

1. Counting moving objects.
2. Limiting the traverse of a mechanism.

2.16.1. Eddy Current Proximity Sensors

Working principle :

When a coil is supplied with an alternating current an alternating magnetic field is produced. If there is a metal object in close proximity to this attending magnetic field, then eddy currents are induced in it. The eddy currents themselves produce a magnetic field which *distorts* the magnetic field responsible for their production. Consequently, the *impedance of the coil changes and so the amplitude of the alternating current. This change, at some preset level, can be used to trigger a switch.*

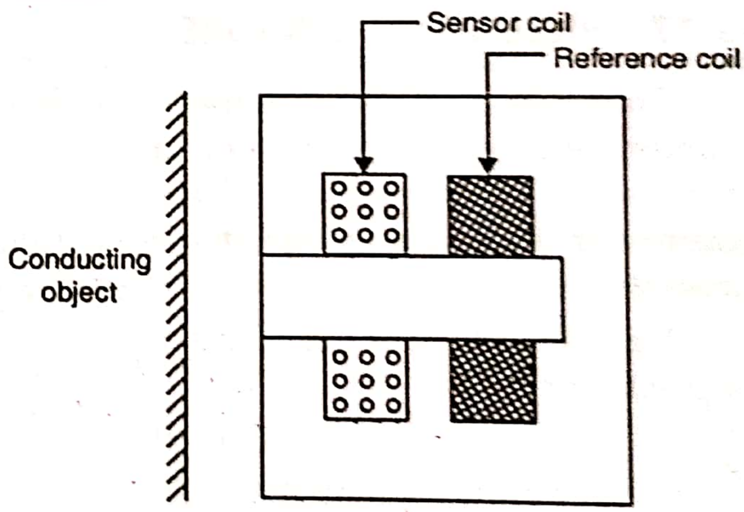

Fig. 2.43. Eddy current proximity sensor.

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Fig. 2.43 shows the basic form of an eddy current proximity sensor. It is *used for the detection of non-magnetic but conductive materials.*

Advantages :

(*i*) Small in size.

(*ii*) Relatively inexpensive.

(*iii*) High flexibility.

(*iv*) High sensitivity to small displacements.

2.16.2. Capacitance Proximity Sensor

Fig. 2.44 shows a schematic diagram of a capacitance proximity sensor.

— It consists of a simple plate (one of the forms), with the object (*earthed*) acting as the other plate.

— As the object approaches the sensor, separation between the plate of the capacitor and object changes which becomes significant as the object is close to the sensor.

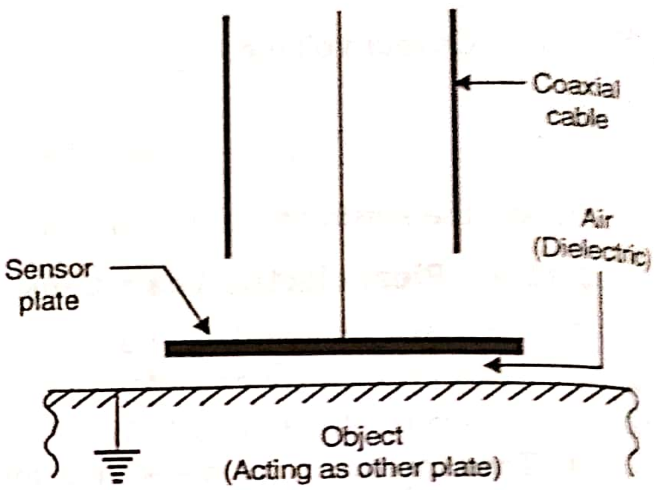


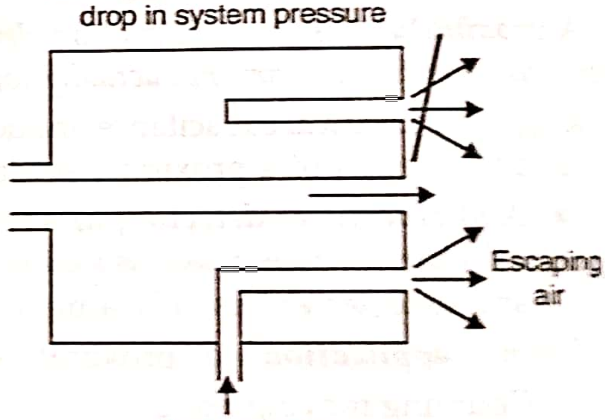
Fig. 2.44. Capacitance proximity sensor.

2.16.3. Inductive Proximity Switch

— An inductive proximity switch consists of a coil wound round a core.

— When the end of the coil is close to a metal object its *inductance changes*. This change can be monitored by its effect on a resonant circuit and the change used to trigger a switch.

- It can only be used *for the detection of metal objects* and is best with ferrous metals.



(a)

escapes and in doing so also *reduces the pressure* in the nearby sensor output port. However, if there is a close by object, the air cannot so readily escape and result is that the *pressure increases* in the sensor output port. The output pressure from the sensor thus depends on the proximity of objects.

- Pneumatic sensors are used for the *measurement of the displacements of fractions of millimeters in ranges which typically are about 3 to 12 mm.*

2.18 LIGHT SENSORS

1. **Photodiodes :**

   "Photodiodes" are semiconductor junction diodes which are connected into a circuit in reverse bias, so giving a very high resistance, so that when light, falls on the junction the diode resistance drops and the current in the circuit rises appreciably

   — A photodiode can be used as a variable resistance device controlled by the light incident on it.

   — These diodes have a *very fast response to light.*

2. **Phototransistors :**

   The phototransistors have a light-sensitive collector-base P-N junction. When there is no incident light there is a very small collector-to-emitter current. When light is incident, a base current is produced that is *directly proportional to the light intensity.* This leads to the production of a collector current which is then a *measure of the light intensity.*

   — Phototransistors are often available as integrated packages with the phototransistor connected in a Darlington arrangement with a conventional transistor (Fig. 2.46). Since this arrangement gives a higher current gain, the device gives a *much greater collector current for a given light intensity.*

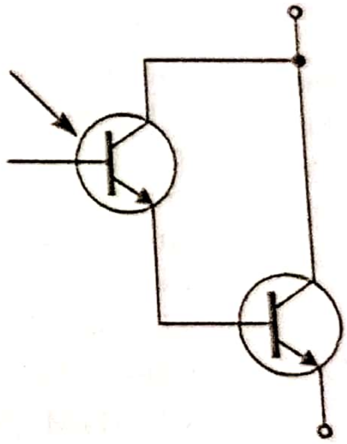


Fig. 2.46. Photo Darlington.

3. **Photoresistor :**

   It has a *resistance* which depends on the intensity of the light falling on it, *decreasing linearly as the intensity increases.*

   — The cadmium sulphide photoresistor is most responsive to light having wavelengths shorter than about 515 nm and the cadmium selinide photoresistor for wavelengths less than about 700 nm.

- An array of light sensors is often required in a small space in order to determine the variations of light intensity across that space.

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... may be sensed.

2.29. MEASUREMENT OF VELOCITY/SPEED

2.29.1 Measurement of Linear Velocity

The following types of transducers are used (in the analogue methods) for measurement of *linear velocity* (first derivative of displacement).

1. Electro-magnetic transducers
   (i) Moving magnet type.
   (ii) Moving coil type.
2. Seismic type transducrs.

Electro-magnetic transducers :

An electro-magnetic transducers utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance. This is the *most commonly used transducer for measurement of linear velocities.*

(i) **Moving magnet type.** A moving type electro-magnetic transducer uses *permanent magnet which provides a constant polarizing field.* Fig. 2.71 shows such a transducer. It consists of rod rigidly coupled to the device whose velocity is being measured. The rod is a permanent magnet which is surrounded by a coil.

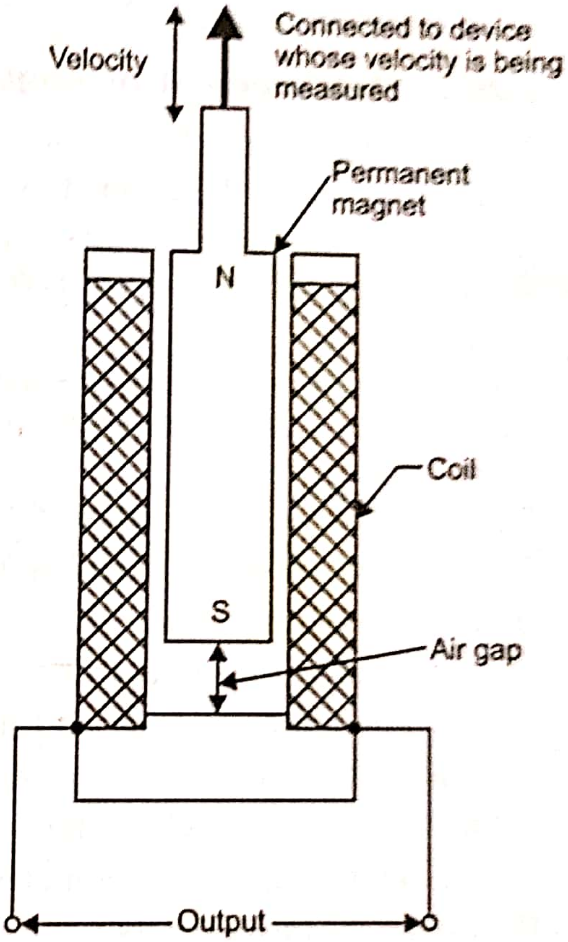

Fig. 2.71. Moving magnet type transducers.

Working. When the magnet moves a voltage is induced in the coil which is *directly proportional to the velocity.* The voltage induced in the coil (placed in a magnetic field) is given by

$$e = BANV \qquad \ldots(2.1)$$

i.e.,

$$e \propto V \qquad \ldots(2.2)$$

where,

B = flux density, Wb/m^2,

A = Area of coil, m^2,

N = Number of turns of coil, and

V = Relative velocity of magnet with respect to coil.

The direction of motion is determined by the polarity of the output voltage.

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Advantages:

1. The output voltage is linearly proportional to velocity.
2. Negligible maintenance (due to absence of mechanical surfaces/contacts).
3. Can be employed as event markers which are robust and inexpensive to manufacture.

Disadvantages:

1. Limited frequency response.
2. Unsuitable for measurement of vibrations.
3. Stray magnetic fields adversely affect their performance.

(ii) **Moving coil type.** This type of transducer operates essentially through the action *of a coil moving in a magnetic field; the voltage generated in the coil being proportional to the velocity of the coil.*

The *advantages* of this type of transducer are:

- Reduced stray magnetic fields effects due to the whole device being contained in an antimagnetic case.
- More satisfactory arrangement, as the system forms a closed magnetic circuit with a constant air gap.

2.29.2 Measurement of Angular Velocity

Angular velocity may be measured with the help of a *"tachometer."*

A **tachometer** may be defined as follows:

"An instrument which either continuously indicates the value of rotary speed or continuously displays a reading of average speed over rapidly operated short-intervals of time."

Or

"An instrument used for measurement of angular velocity, as of shaft, either by registering the total number of revolutions during the period of contact, or by indicating directly the number of revolutions per minute."

Classification of Tachometers

The tachometers are *classified* as follows:

I. *Mechanical tachometers :*

(*i*) Hand speed indicator.

(*ii*) Revolution counter and timer.

(*iii*) Tachoscope.

(*iv*) Centrifugal tachometers.

(*v*) Vibrating reed tachometers.

II. *Electrical tachometers :*

(*i*) D.C. tachometer generators

(*ii*) A.C. tachometer generators

(*iii*) Photoelectric tachometers (or Speed-meter)

(*iv*) Eddy current or drag-cup tachometer.

(*v*) Capacitive tachometer.

(*vi*) Stroboscopic tachometers.

2.29.2.1 Mechanical tachometers

1. ***Hand speed indicator:*** Refer to Fig. 2.72.

This tachometer has an integral stopwatch and counter with automatic disconnect

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5.3 CONTROLLERS

5.3.1. Introduction

Whereas the ***open-loop control*** is essentially just a *switch on-switch off form of control*, but with a ***closed-lop control systems*** *a controller is used to compare the output of a system with the required condition and convert the error into a control action designed to reduce the error.*

- The *digital control* is used when the computer is in the feedback loop and exercising control in this way.
- The term *programmable logic control* (PLC) is used for a simple controller based on

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a *microprocessor* and operates by examining the input signals from sensors and carrying out logic instructions which have been programmed into the memory.

Here we shall discuss about closed-loop control.

5.3.2. Control Modes

The various types of control modes (*i.e.*, the ways in which controllers can react to error signals) are:

1. Two-step mode.
2. Proportional mode (P).
3. Derivative mode (D).
4. Integral mode (I).
5. Combinations of modes: PD, PI and PID.

The above modes can be achieved by a controller by means of pneumatic circuits, analogue electronic circuits involving operational amplifiers or by the programming of a microprocessor or computer.

5.3.3. Two-step Mode

In such a mode the controller is essentially just a switch which is activated by the error signal and supplies just as an on-off correcting signal.

Example: The *'bimetallic strip'* that may be used with a simple temperature control system.

- In this type of mode control action is *discontinuous.*

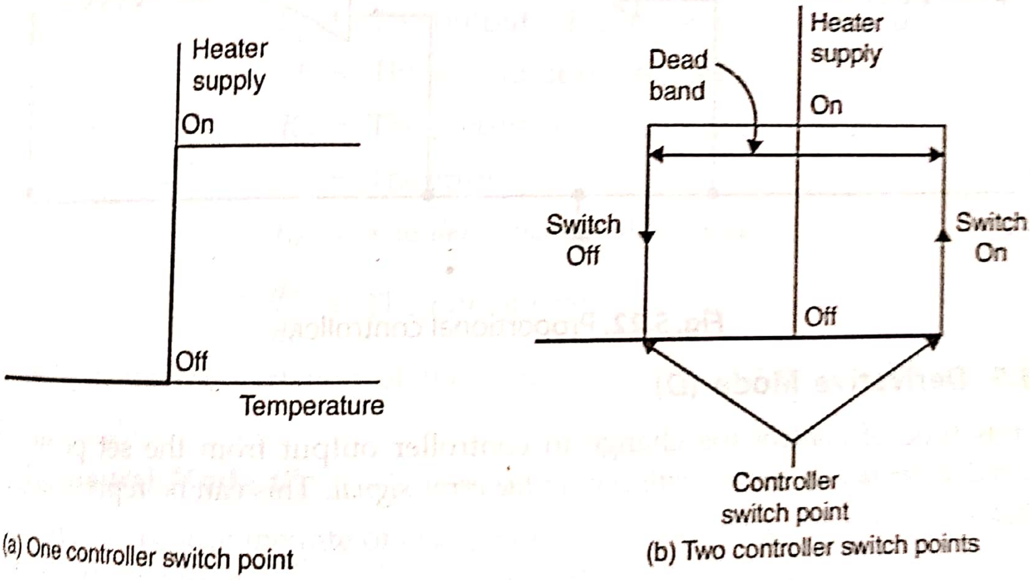

Fig. 5.20. Two-stop control with one and two controller switch points.

Fig. 5.20(*a, b*) shows two-step control with one controller switch point and two controller switch points respectively.

5.3.4. Proportional Mode (P)

In a proportional-mode method of control, the size of the controller is *proportional to the size of the error* (whereas in a two-step method of control the control output is either an 'on' or an 'off' signal, irrespective of the magnitude of the error).

Fig. 5.21 shows the output variations of a proportional-mode controller, with the size and sign of error.

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Proportional band is the range of errors over which the linear relationship between controller output and error tends to exist. The equation of straight line within the proportional band can be represented by :

Change in output of the controller from set point $= K_P \cdot e$ ...(5.66)

where, I_o = The controller output percentage at zero error,

I_{out} = The controller output percentage at error e,

K_P = A constant, and

e = The error.

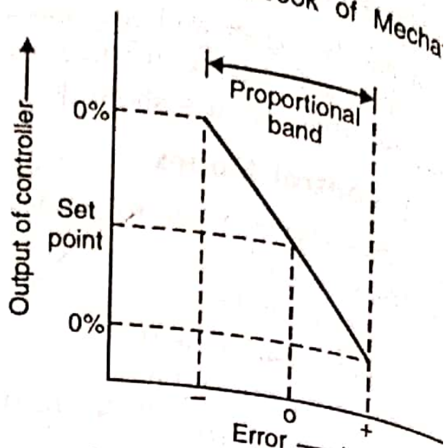

Fig. 5.21. Proportional band.

- Fig. 5.22 shows a summing operational amplifier with an inverter used *proportional controller.*

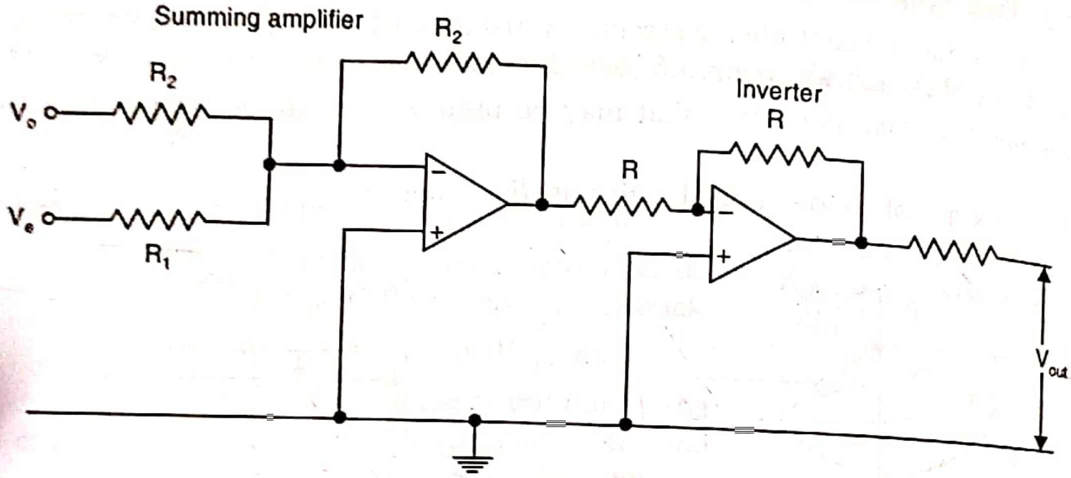

Fig. 5.22. Proportional controller.

5.3.5. Derivative Mode (D)

In this type of control the change in controller output from the set point value *proportional to the rate of change with time of the error signal.* This can be represented by t equations:

$$I_{out} - I_o = K_D \frac{de}{dt} \quad \text{...(5.}$$

where, I_o = The set point output value, and

I_{out} = The output value that will occur when the error e is changing at the rate $\frac{de}{dt}$, and

K_D = Constant of proportionality.

Fig. 5.23, shows the output of controller that results when there is a constant rate of change of error with time.

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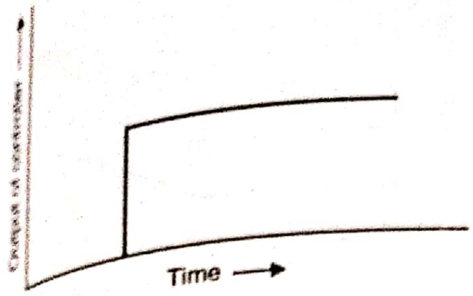

Fig. 5.23. Derivative control.

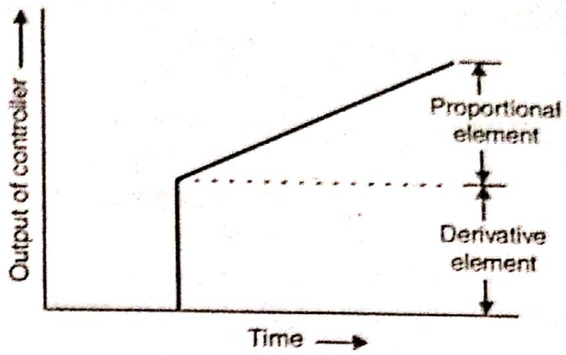

Fig. 5.24. PD control.

5.3.5.1. PD controller

Since derivative controllers do not respond to steady-state error signals (as with these signals the rate of error change with time is zero), *the derivative control is always combined with proportional control.*

– The derivative part *responds to the rate of change;*

– The proportional part gives a *response to all error signals* (including steady signals).

In a PD (proportional plus derivative) controller the change in the output of controller from the set point value is given by:

$$I_{out} - I_o = K_P\, e + K_D \frac{de}{dt} \qquad \text{...(5.68)}$$

where,

I_{out} = The output when error is e,

I_o = The output at the set point,

K_P = The *proportionality constant*,

e = The error,

K_D = The *derivative constant*, and

$\frac{de}{dt}$ = The rate of change of error.

Fig. 5.24 shows the variation of the output of controller when the error changes constantly.

5.3.6. Integral Mode (I)

In this type of control the rate of change of the output of the control I is proportional to the input error signal e.

i.e.,

$$\frac{dI}{dt} = K_I\, e \qquad \text{...(5.69)}$$

where,

K_I = The constant of proportionality.

Integrating the above equation we get

$$\int_{I_o}^{I_{out}} dI = \int_0^t K_I e\, dt$$

or, $$I_{out} - I_o = \int_0^t K_I e\,dt \qquad ...(5.70)$$

where, I_o = The output of controller at zero time, and

I_{out} = The output of controller at time t.

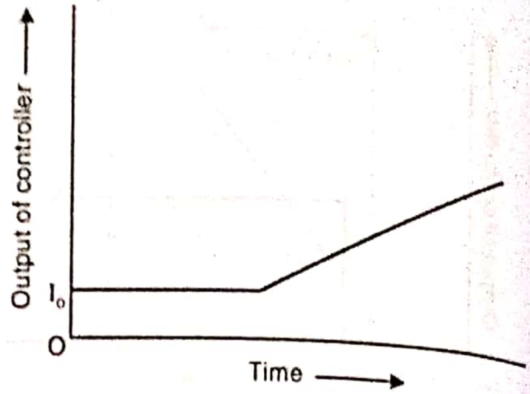

Fig. 5.25. Integral control.

Fig. 5.25 shows the action of an integral controller when there is a constant error input to the controller:

— When the controller output is constant, the error is zero;

— When the controller output varies at a constant rate the error has a constant value.

5.3.6.1. PI controllers

Normally, the integral mode is not used alone but is frequently used in conjunction with the proportional mode. The equation of the PI control system is given as :

$$I_{out} - I_o = K_P e + \int K_I e\,dt \qquad ...(5.71)$$

Fig. 5.26, shows how the system reacts when there is an abrupt change to a constant error:

— The error gives rise to a proportional controller output which remains constant since there is no change in error;

— On this is then superimposed a steadily increasing controller output due to the integral action.

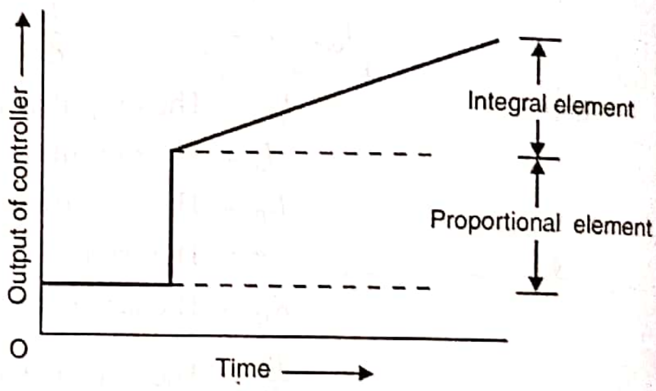

Fig. 5.26. PI control.

5.3.7. PID Controllers

PID controller is one in which all the three modes of control, Proportional (P), Integral (I) and Derivative (D) are combined together. In such a controller there *is no offset error and tendency for oscillations is reduced.*

The equation of this controller is written as :

$$I_{out} - I_o = K_P e + K_I \int e\,dt + K_D \frac{de}{dt} \qquad ...(5.72)$$

where, I_{out} = The output from the controller,

I_o = The set point output when there is no error,

K_P = The proportionality constant,

e = Error,

K_I = The integral constant, and

K_D = The derivative constant.

Fig. 5.27, shows an operational amplifier PID circuit.

Here,
$$K_P = \frac{R_1}{R+R_D};\ K_D = R_D C_D;\ K_I = \frac{1}{R_1 C_1}$$

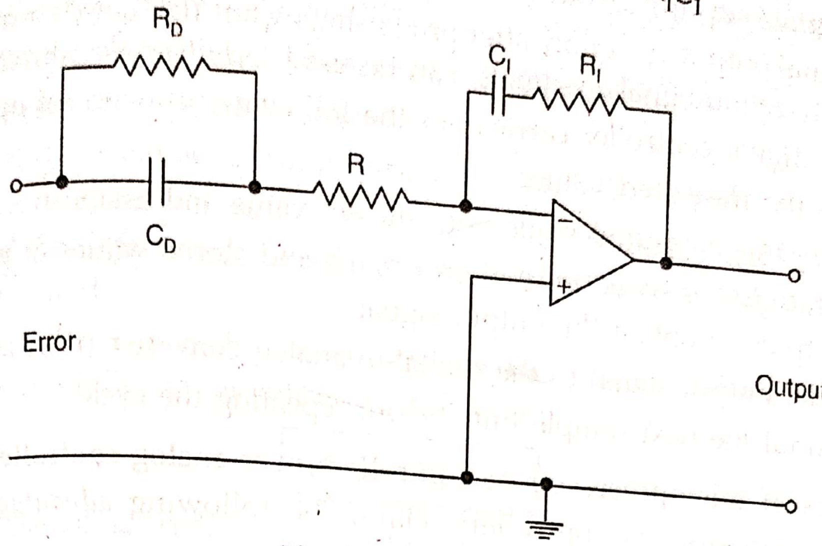

Fig. 5.27. PID circuit.

5.3.8. Digital Controllers

The **digital controllers require inputs which are digital, process the information in digital form and give an output in digital form.*

The controller performs the following functions:

(*i*) Receives input from *sensors*;

(*ii*) Executes control programs;

(*iii*) Provides the output to the correction elements.

— As several control systems have analogue measurements an analog-to-digital converter (ADC) is used for the inputs.

Fig. 5.28 shows the digital closed-loop control system which can be used with a continuous process:

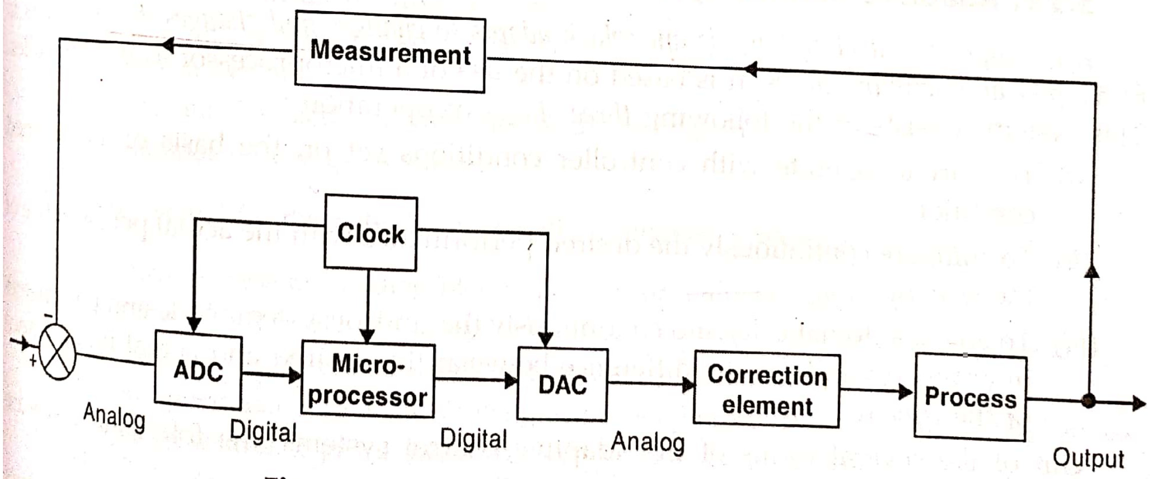

Fig. 5.28. Digital closed-loop control system.

— The *clock* supplies a pulse at regular time intervals and dictates when samples of controlled variables are taken by the *ADC*.

* The term *digital control* is used when the digital controller, basically microprocessor, is in control of the closed-loop control system.

— These samples are then converted to digital signals which are compared by the *microprocessor* with the set point value to give the error signal.

— The error signal is then processed by a *control mode* (initiated by the microprocessor) and digital output is produced.

— The digital output, generally after processing by an ADC since correcting elements generally require analog signals, can be used *to initiate the corrective action.*

Basically, a digital controller carries out the following sequence of operations:

- *Samples* the measured value.
- *Compares* this measured value with the set value and establishes the error.
- *Makes calculations* based on the error value and stored values of previous inputs and outputs to obtain the output signal.
- *Sends* the output signal to the digital-to-analog converter (DAC).
- *Waits* until the next sample time before repeating the cycle.

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