regulating system is a feedback control system in which the set point (reference input) or the desired output (controlled signal) is either constant or slow varying with respect to time and in which the primary task is to maintain the actual output at the desired value in the presence of disturbances.

1.8 PROCESS CONTROL SYSTEMS

Process control systems are feedback control systems, which regulate process outputs or variables such as pH level, temperature, pressure flow, humidity, distribution, batch reaction, etc. Obtaining a process model and then studying its dynamic behaviour are must before designing such control mechanisms.

1.9 SOME EXAMPLES OF CONTROL SYSTEMS

The following are some examples of control systems:

1.9.1 Steam turbine speed control system

A steam turbine speed control system is shown in Fig. 1.17. Whenever load on the turbine changes, the turbine speed changes. The governor acts as a controller and the valve as final control element. The centrifugal governor operates an amplifier, which regulates the opening and closing of valve, and thus, the steam flow passes from boiler on to the blades of turbo-generator. As the generator load increases, the turbine speed reduces. To keep the turbine rotational speed at a reference level (set point), the valve is opened more so that more steam flow takes place from boiler to turbine and to cope up with the difference in speed from the current speed level to the reference speed level and vice-versa in the case of off-loading, thus bringing the turbine to the reference speed.

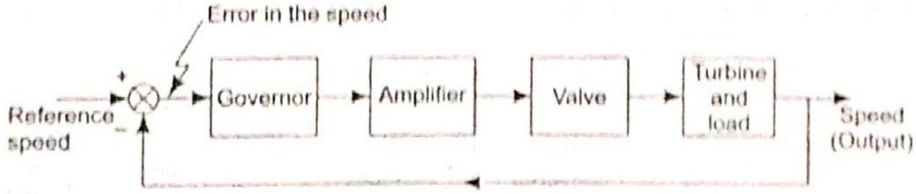

Figure 1.17 Closed-loop speed control of a steam turbine

1.9.2 Manual feedforward and feedback control of temperature

Manual feedforward and feedback control of temperature is shown in Fig. 1.18. A human being closes or opens the valve depending on the flow rate of steam and the temperature of water inside the heater. Thus, it is a closed-loop control system with both feedforward and feedback modes concurrently. The control of flow is based on the feedback of the temperature and the feedforward control of the steam flow rate.

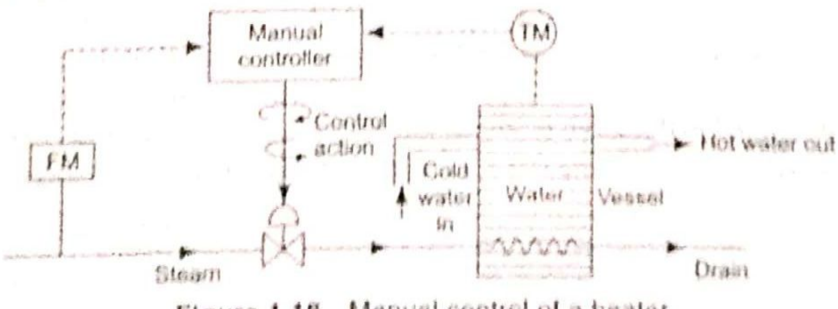

Figure 1.18 Manual control of a heater

1.9.3 Speed control of a single-phase induction motor

Speed control of a single-phase induction motor is shown in Fig. 1.19. A pre-calibrated voltage V corresponding to the reference speed θ_r is applied to the comparator as a set point. The feedback sign is transduced voltage signal V_{θ_f}, generated by tachogenerator corresponding to the instantaneous le of the motor speed θ_0.

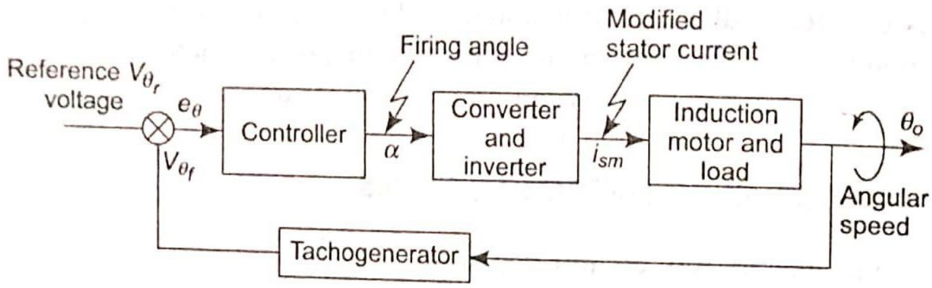

Figure 1.19 Feedback speed control of an induction motor

The controller takes in the error signal (difference of the set point voltage and feedback voltage) an generates a firing angle α for the conduction of SCRs in converter, thus giving different duty cycle The PWM technique may be applied to generate a desired current pulse i_{sm}. This current signal i_{sm} the stator current increases or decreases the induction motor speed accordingly. The speed of inductio motor is tried to be kept at the reference level θ_r (desired angular speed).

1.9.4 Computer-based servo mechanism

Figure 1.20 shows a closed-loop control configuration for velocity control of servo motor.

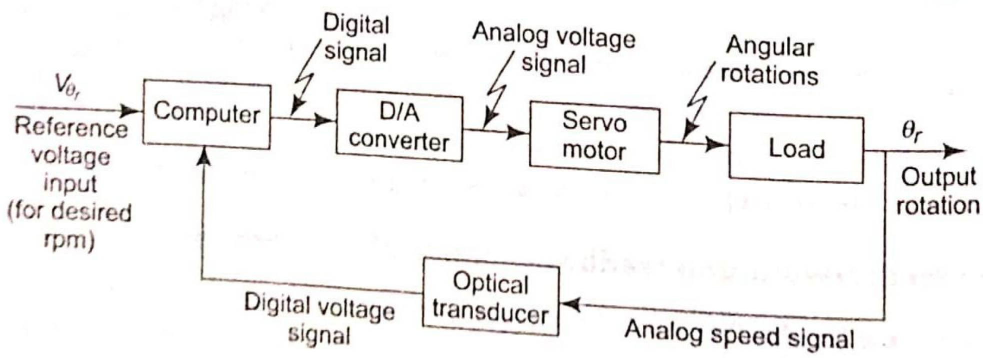

Figure 1.20 A computer-based and closed loop control of servo motor

A calibrated voltage (reference) for desired speed (rpm) V_{θ_r} is applied as an input to the compute Here, the computer acts as a comparator as well as a controller. The digital signal is converted int analog signal by using a signal conditioning device, namely a digital-to-analog converter (DAC). controlling voltage is applied to the servo motor so as to get a controlled angular rotation from it. Sinc it is a closed-loop configuration, the angular speed of servo motor will be changed according to th magnitude of load.

1.9.5 Open-loop ceiling fan control system

Figure 1.21 depicts an open-loop control scheme of a ceiling fan. In the absence of voltage regulator and a feedback, the ceiling fan will always run at a constant rpm. However, it can be turned ON and OFF with the help of a simple electrical switch.

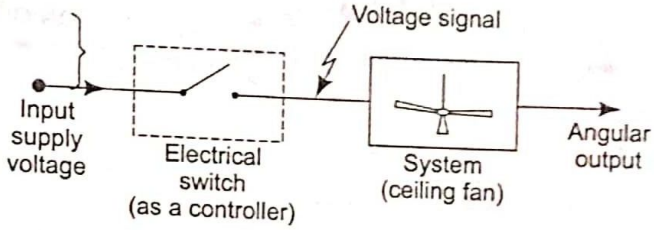

Figure 1.21 An open-loop control of a ceiling fan

1.9.6 Closed-loop ceiling fan control system

A manual control system is shown in Fig. 1.22. Here, the fan's speed is regulated with the help of a voltage regulator. The voltage regulator acts as a final control element. It can be considered as an integral component of the ceiling fan. The feedback is essentially sensory organs of human beings and the human brain is a controller. It necessitates a correcting signal or an actuating signal on the basis of prevailing or instantaneous room temperature and desired room temperature.

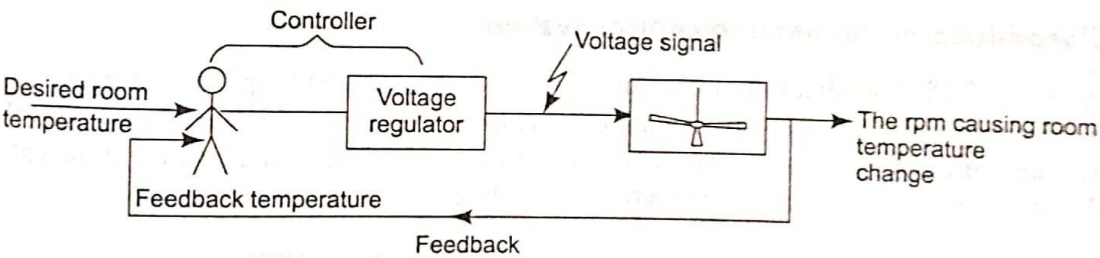

Figure 1.22 A closed-loop control of a ceiling fan

1.9.7 Open-loop control of traffic light system

In our country, the traffic light system is by and large open-loop except at places with a traffic policeman-controlling road crossing. The open-loop traffic signalling is shown in Fig. 1.23.

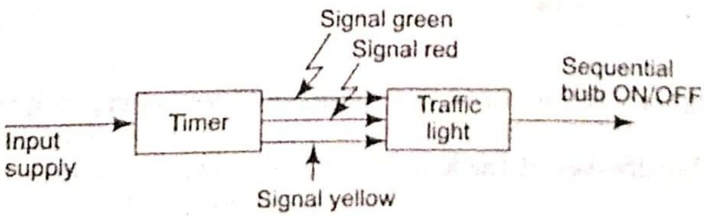

Figure 1.23 An open-loop traffic light control system

The time is pre-programmed for fixed durations and it goes green, amber, and red sequentially.

1.9.8 Closed-loop traffic light control system

A closed-loop traffic light control system can be proposed as shown in Fig. 1.24.

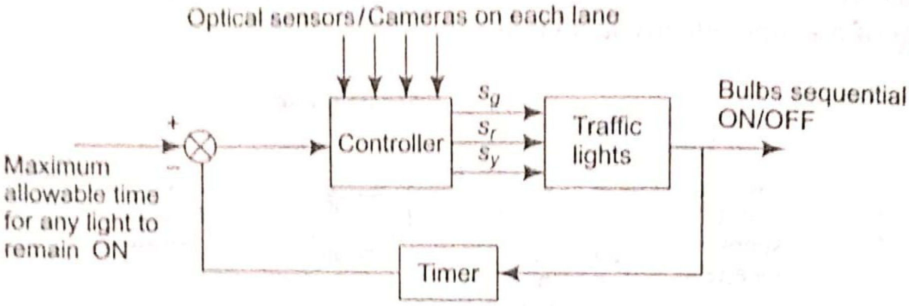

Figure 1.24 A closed-loop traffic light control system

As shown in the Fig. 1.24, a maximum allowable time is kept as reference. This maximum allowa time for a particular light to remain ON, refrains from creating a traffic jam's snarls or chaos. T optical sensors or cameras have to supply the number of vehicles count in each lane to the controll Although, the lights will be sequentially controlled as in the case of open-loop control, their ON a OFF timings will be regulated by the controller. It will no more remain a preset value. Rather it w acquire varying ON and OFF timings, which will be optimal in nature and guided by the counts be supplied by the individual camera/optical sensor to the controller.

1.9.9 Closed-loop water heating control system

As shown in Fig. 1.25, a feedback control system configuration (closed loop) for water heating syst measures the outlet water temperature, compares it with the expected value, and determines the err Comparator determines error. Error value is then used to control opening and closing of the valve at steam inlet in order to obtain the desired water temperature.

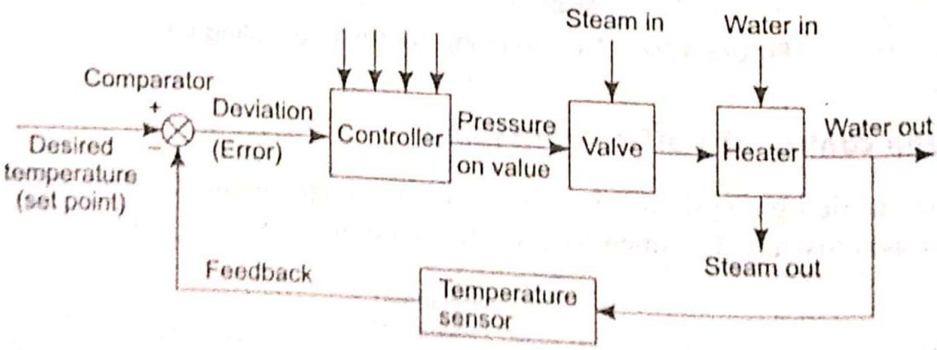

Figure 1.25 A closed-loop control of water heating system

1.9.10 Closed-loop feedforward tank height/level control system

This control system is shown in Fig. 1.26. In feedforward control, a disturbance variable is measu and the manipulated variable is changed before the output is affected. Often comparator is conside to be within the controller as comparator is a very simpler device, i.e., just a subtractor. In the ab case, the inlet flow rate can be changed by upstream process unit and is, therefore, considered to be a disturbance variable. To maintain a constant tank height, inlet flow rate is measured and the output flow rate is manipulated.

The disadvantage of the feedforward control strategy is insensitivity to uncertainty. That is, if the inlet flow rate is not perfectly measured or the outlet flow rate cannot be manipulated perfectly, the tank height will not be perfectly controlled.

The feedforward control strategy is seldom used alone in practical control. It is always combined with feedback control so as to account for uncertainty. The example discussed below is one such case.

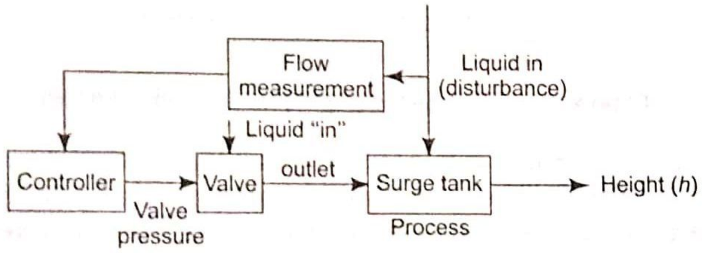

Figure 1.26 A feedforward level control system

1.9.11 Closed-loop feedforward/feedback tank height/level control system

Figure 1.27 illustrates a composite feedforward and feedback control strategy of industrial utility. It is quite robust and compensates for a larger range of uncertainties arising during the control system operation.

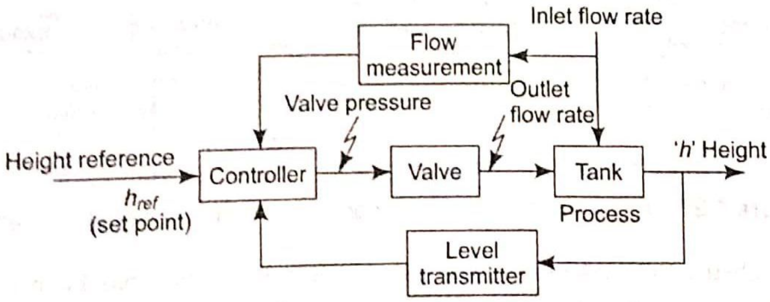

Figure 1.27 A feedforward + feedback liquid level control system

As shown in the scheme, the feedforward allows immediate controlling action to be taken before the inlet flow rate affects the tank height/liquid level. The feedback controller compensates for the outlet flow rate needed to maintain desired level, in spite of the errors in the inlet flow rate measurement.

1.9.12 Production control system

In the production control system shown in Fig. 1.28, the production rate will be regulated as per the floating demand in the sales territories/clientele regions.

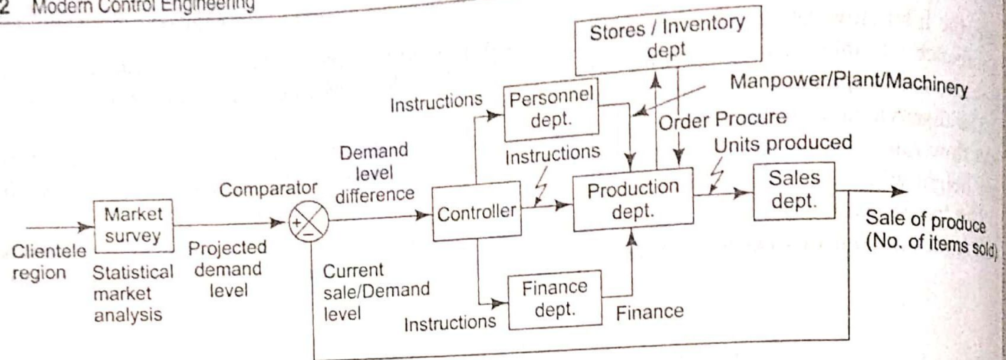

Figure 1.28 A closed-loop production control system

A projected demand level is always kept as a reference over a specific period. The difference in the projected demand level and current demand level is given to the controller. The controller may be Managing Director of a company or Chief Executive Officer (CEO) of a big corporation.

The controller issues further directions or instructions (actuating signals) to the various units, such as Finance Department, Personnel Department, so that the production rate may be regulated in the close coordination of these various functional units/departments of an organization involved in the production sector.

1.9.13 Economy control system

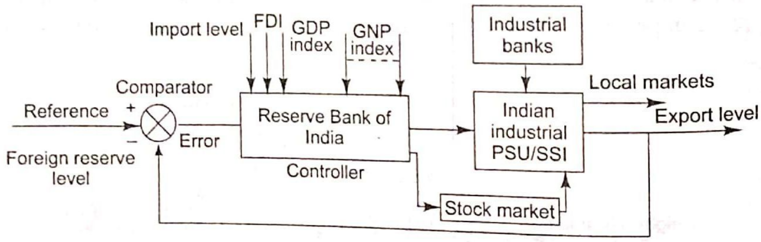

Figure 1.29 A closed-loop economy control system (in an abstract sense)

In Fig. 1.29, an abstract closed-loop model of economy regulation has been depicted. The Chief Economy Controller in any country is its central bank, e.g., RBI in India. RBI issues instructions from time to time on the basis of import/export levels, GDP, GNP, political factors, and others to the chief economy players, such as stock exchanges/markets, industrial loan sanctioning modes/banks, and the industries involved in the production sector. This way, economy is regulated.

1.9.14 Robot-arm control system

In the robot-arm control system shown in Fig. 1.30, a television camera captures the instant trajectories/traversals by the robot arm.

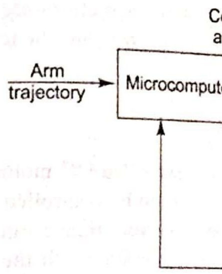

Figure 1.

The camera captures the orienta
the television camera. A standard
data, which may be coordinates of
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1.9.15 Quality control system

As shown in Fig. 1.31, quality
quality control unit of the company

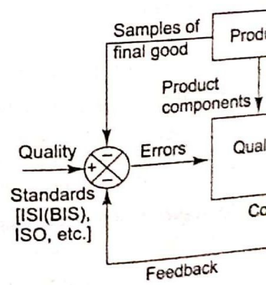
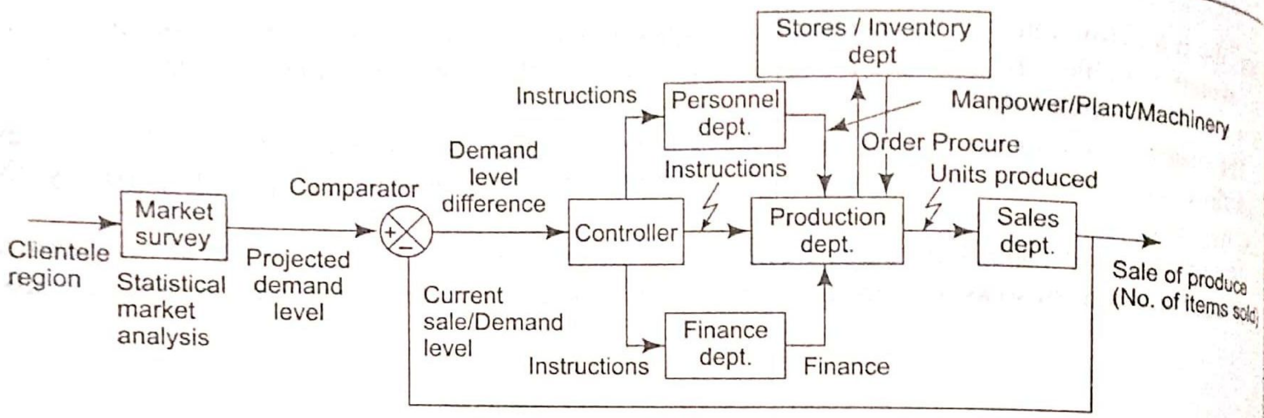


Figure 1.31

The head of a quality control uni
for their quality checks with refere
locally, which may be producer an
safety rules as supplied by variou
Indian Standards (ISI), ISO, and IE
customer satisfaction (based on the
with the laid standards are taken u



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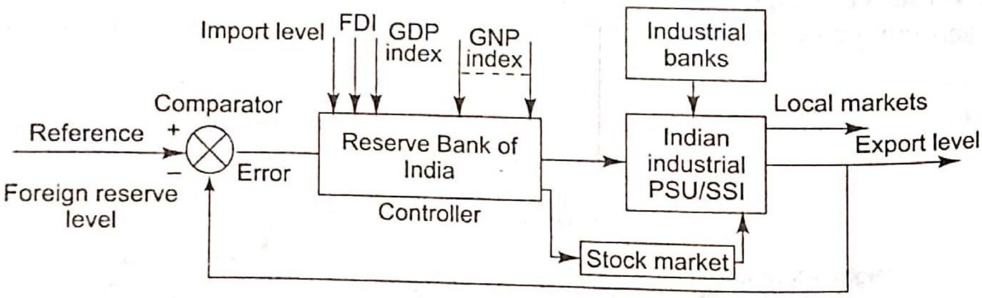

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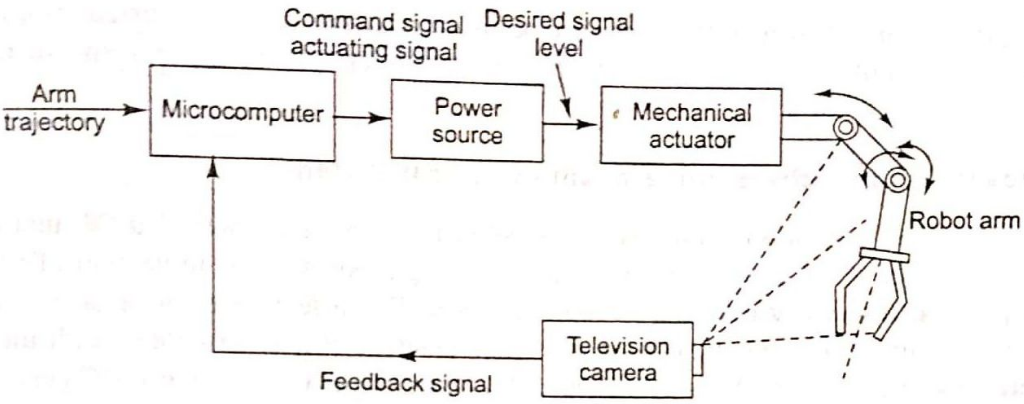

Figure 1.30 A closed-loop robot arm control system

The camera captures the orientation of the robot arm. A microcomputer receives the signals sent by the television camera. A standard program is already present in this computer. It acts as a reference data, which may be coordinates of the destination to which the arm has to approach/reach. The computer generates command signals/actuating signals for the power source and in turn the power source supplies the desired amount of power to the various sections of the robot arm. Such a robot arm is widely used in assembly line in production units of industries.

1.9.15 Quality control system

As shown in Fig. 1.31, quality control for the goods produced by a company is performed by the quality control unit of the company.

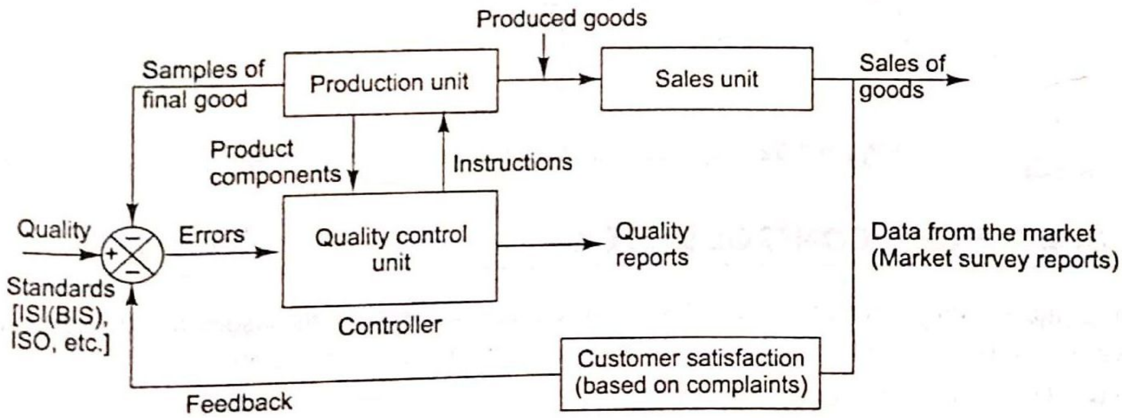

Figure 1.31 A closed-loop quality control (QC) system

The head of a quality control unit acts like a controller. A few samples on random lots are picked up for their quality checks with reference to the standards or quality norms. These norms are generated locally, which may be producer and customer specific. They can also be the global specifications and safety rules as supplied by various national and international bodies/societies/organizations, e.g., Indian Standards (ISI), ISO, and IEEE. There is feedback from the market as well. It may be level of customer satisfaction (based on their complaints). The difference of these feedback signals (variance) with the laid standards are taken up for action by the quality control unit. Quality control asks for various components and their quality checks are performed. The necessary instructions are issued by the quality control unit for the production unit for necessary quality control and hence product improvement.

1.9.16 Closed-loop electrical drive position control system

Figure 1.32 illustrates a position control with the help of an armature-controlled DC motor. The DC motor and load can be considered as the plant, and the output position has to be controlled as per the reference input. It is a servo system or a servo mechanism. The difference error voltage signal V_E (the difference of the output position θ_0 and the reference position θ_{ref}) is generated with the help of a potentiometer. The error voltage V_E is amplified and it changes the field current of DC generator. Here, a pair of potentiometers is used for error detection and hence it is called a *potentiometric error detector*. The change brought in field current due to V_E ultimately changes the speed of the motor and tries to bring it to a level in which V_E becomes zero ($\theta_0 = \theta_{ref}$) and the goal is achieved. The motor moves the load through the gear trains such that the output position θ_0 becomes equal to the reference position θ_{ref}. Missile launch and guiding system uses similar kind of position control system.

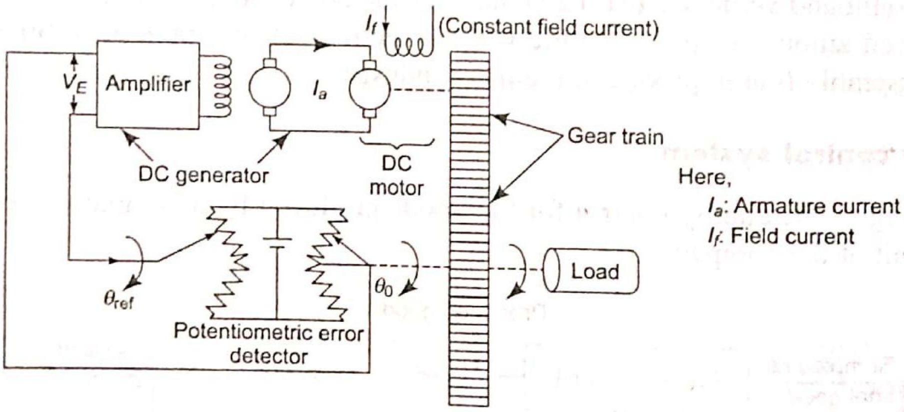

Figure 1.32 An electrical drive position control system

1.10 DESIGNING A CONTROL SYSTEM

Designing and development of a control system requires the following issues to be addressed in a sequence. It needs a methodical approach as discussed in various steps below.

Step 1: Define the control objective.

Step 2: Select input variables of the system plant needing a control action and classify the input variables as

(a) Manipulated variable(s)

(b) Disturbance variable(s)

These inputs may change continuously or at discrete time intervals.

Step 3: Finalize output variables of the system plant and classify the output variables as

(a) Measured output variable(s)

(b) Unmeasured output variable(s)

The measurement of output variables may be carried out continuously or at discrete time intervals.

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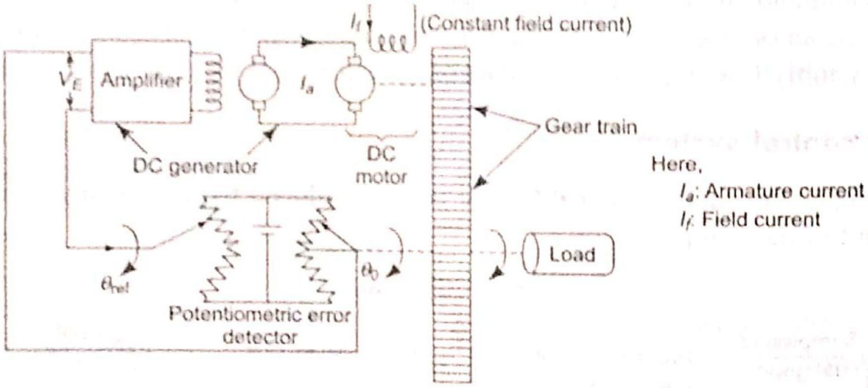

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- (a) Measured output variable(s)
- (b) Unmeasured output variable(s)

The measurement of output variables may be carried out continuously or at discrete time intervals.

Scanned with CamScanner

Step 4: Find the operating constraints and classify them as
(a) Hard constraint
(b) Soft constraint

For example, the full height of the water tank in a tank level control system is a hard constraint so as to avoid any wastage of water due to overflow. Any intermediate height or level, at which the water tank may be desired to be filled can be considered as a soft constraint.

The soft constraints may be compromised but hard constraints should never be compromised.

Step 5: Find the operating characteristics of the system plant and classify them as
(a) Continuous
(b) Batch
(c) Semi-continuous or semi-batch

Continuous process operates for a very long period before shutdown and the operating conditions remain relatively constant, for example, in oil refineries. Batch processes have varying operating conditions and their operational time is short or limited, for example, in a batch reactor. A semi-batch or semi-continuous process lies between above two classifications, i.e., continuous and batch.

Step 6: Considerations for safety, environment, and economy are to be ascertained. The instrumentation involved in the control system should be fail-safe (fail proof).

Step 7: Control structure depending upon the nature of the system plant has to be chosen out of the following two categories:
(a) Feedback
(b) Feedforward

A combination of feedback and feedforward can also be used for faster and safer control.

A control system has the following three main instrumentation blocks:

(a) Measurement device or sensor (e.g., temperature, level, or pressure sensor). These devices convert the measured value into a current or voltage signal.
(b) Manipulated input device or actuator (e.g., pneumatic valve)
(c) Controller

On the basis of the measurements, the controller manipulates the input device for the control of the system output.

The current-to-pressure conversion takes place in I/P (current-to-pneumatic) converters. In digital control, digital signal supplied by a digital sensor to a controller is converted into analog signal with the help of D/A converter or D/I (digital-to-electronic analog current). Then an I/P converter may be employed. Before implementing the controller, the various instrumentation and control blocks involved in the control loop must be simulated and analysed.

Nowadays, plant or system models are often 'embedded' in the controller itself on a single chip. The advantage of this is that the controller can use a process model to anticipate the effect of control actions. These are very popularly called *embedded controllers*.

The control system is an interdisciplinary subject as the control of any given system may be desired. The subsequent chapters gradually unfold the details of control system design, analysis, and development in a structured and scientific manner.