Control Systems

- A control system is a collection of components working together under the direction of some machine intelligence.
- In most cases, electronic circuits provide the intelligence, and electromechanical components such as sensors and actuators provide the interface to the physical world.
- A good example is the modern automobile. Various sensors supply the on-board computer with information about the engine's condition. The computer then calculates the precise amount of fuel to be injected into the engine and adjusts the ignition timing.
- Control systems can be classified into two groups:
  - (i) open-loop and (ii) closed-loop.
- In an **open-loop system** [Figure 6.1(a)],
  - no feedback is used, so the controller must independently determine what signal to send to the actuator.
  - The trouble with this approach is that *the controller never actually knows if the actuator did what it was supposed to do.*

Control Systems

- In a **closed-loop system,** also known as a *feedback control system*, the output of the process is constantly monitored by a sensor [Figure 6.1(b)].
- The sensor samples the system output and passes this informatio back to the controller.
- Because the controller knows wha the system is actually doing, it can make any adjustments necessary to keep the output where it belongs.
- This self-correcting feature of closed-loop control makes it preferable over open-loop control in many applications.

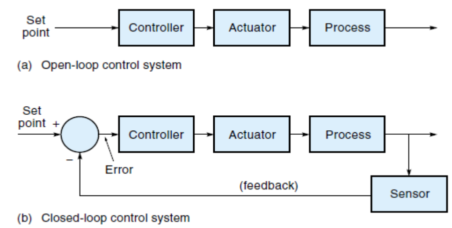


Figure 6.1 Open- and closed loop systems.

Control Systems

- the "heart" of the control system is the **controller,** an analog or digital circuit that accepts data from the sensors, makes a decision, and sends the appropriate commands to the actuator.
- the controller tries to keep the **controlled variable** — such as temperature, liquid level, position, or velocity—at a certain value called the **set point** (SP).
- A feedback control system does this by looking at the **error** (E) signal
  - Error (E) is the difference between where the controlled variable is and where it should be.
  - Based on the error signal, the controller decides the magnitude and the direction of the signal to the actuator.

Feedback Control Systems: example

Example 1: process control system

[Figure 6.2(a)]

- the job of the controller is to maintain a stationary set point despite disturbances—for example, maintaining a constant temperature in an oven whether the door is opened or closed.

Example 2: servomechanism

[Figure 6.2(b)],

- the job of the controller is to have the controlled variable track a moving set point—for example, moving a robot arm from one position to another.

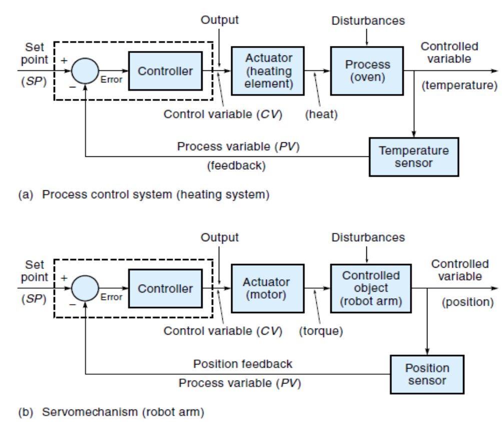


Figure 6.2 Feedback-control block diagrams.

Example: Room temperature control system

- The output signal from a temperature sensing device such as thermocouple, or a resistance thermometer is compared with the desired temperature.
- Any difference or error causes the controller to send a control signal to the gas solenoid valve, which produces a linear movement of the valve stem, thus adjusting the flow of the gas to the burner of the gas fire.

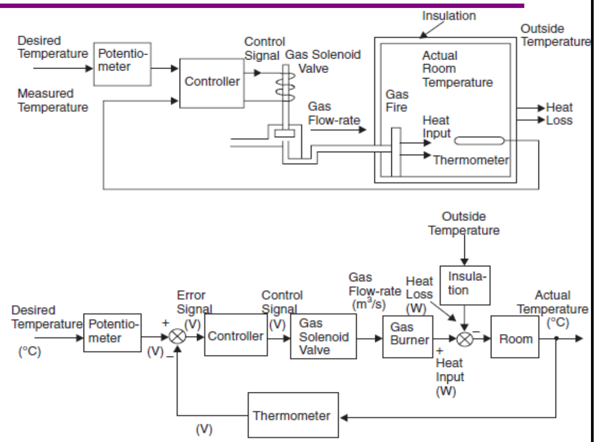


Figure 6.3 Room temperature control system

Example: Elevator control system

- Movement of the control column produces a signal from the input angular sensor which is compared with the measured elevator angle by the controller which generates a control signal proportional to the error.
- This is fed to an electro-hydraulic servo-valve which generates a spool-valve movement that is proportional to the control signal, thus allowing high-pressure fluid to enter the hydraulic cylinder.
- The pressure difference across the piston provides the actuating force to operate the elevator.

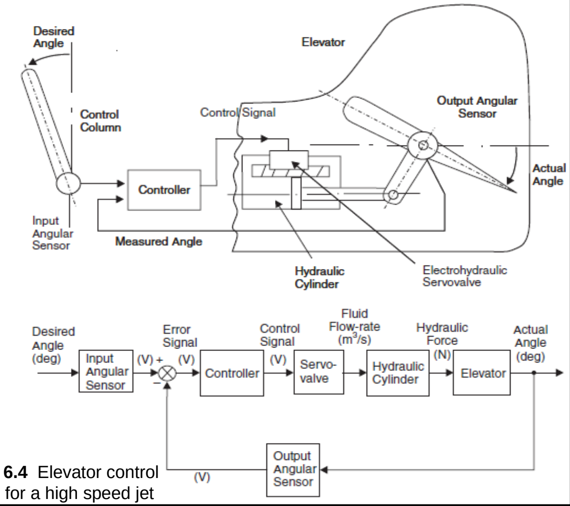


Figure 6.4 Elevator control system for a high speed jet

Example: CNC machine tool

- Information relating to the shape of the work-piece and hence the motion of the machine table is stored in a computer program.
- This is relayed in digital for-mat, in a sequential form to the controller and is compared with a digital feedback signal from the shaft encoder to generate a digital error signal.
- This is converted to an analogue control signal which, when amplified, drives a DC servomotor.
- The output shaft of the servomotor is a lead-screw to which the machine table, the shaft encoder and a tacho-generator (which produces analogue signal proportional to the velocity) are attached .

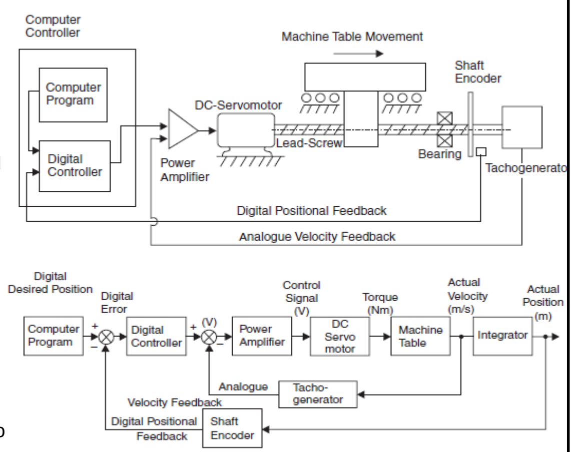


Figure 6.5 CNC machine tool

Example: Ship autopilot control system

- The actual heading of the ship is measured by a gyro-compass, and compared with the desired heading, dialled into the autopilot by the ship's master.
- The autopilot, or controller, computes the demanded rudder angle and sends a control signal to the steering gear.
- The actual rudder angle is monitored by a rudder angle sensor and compared with the demanded rudder angle, to form a control loop.
- The rudder provides a con-trol moment on the hull to drive the actual heading towards the desired heading while the wind, waves and current produce moments that may help or hinder this action.

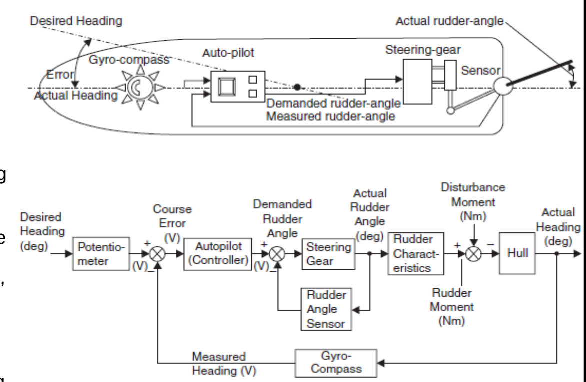
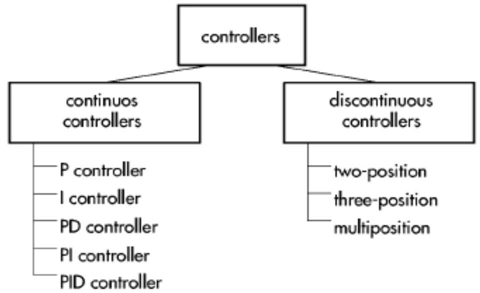


Figure 6.6 Ship autopilot control system

Controllers



Proportional Controllers

- the actuator *applies a corrective force that is proportional to the amount of error*

$$\text{Output}_P = K_P E$$

where,

Output_P = controller output due to proportional control (i.e., the corrective force)

K_P = proportional constant for the system called **gain**

E = error, the difference between where the controlled variable should be and where it is

Example:

Position control system, Figure 6.7.

- A robot arm is powered by a motor/gearhead.
- A potentiometer provides position information, which is fed back to a comparator. This feedback signal is called the **process variable** (*PV*).
- The comparator subtracts *PV* from the set point (*SP*) to determine the error (*E*) as expressed as,

$$E = SP - PV$$

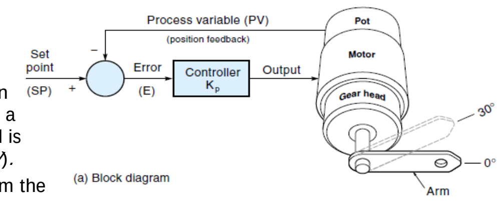
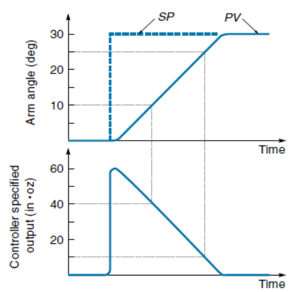


Figure 6.7 A proportional control position system.

Proportional Controllers

- the controller output is proportional to the error.
- This output directs the motor to move in a direction to reduce the error.
- As the position of the arm gets closer to the set point, the error diminishes, which causes the motor current to diminish.
- At some point, the error (and current) will get so small that the arm comes to a stop.



(b) Graphs showing response to change in set point

Proportional Controllers: Problem

Assume that a motor driven arm was originally at 0° and then was directed to move to a new position at 30°. The gain of the system is K_P = 2 in. · oz/deg.

Describe how the controller responds to this situation.

- Originally, the arm is at rest at 0°. When the set point is first changed to 30°, an error signal of 30° results (because the arm is 30° away from where it should be):
  Error = $SP - PV$ = 30° – 0° = 30°
- the initial restoring torque the system would generate:
  $\text{Output}_P = K_P E$ = 2 in. · oz/deg × 30° = 60 in. · oz
  - This means that the motor would initially be directed to create a torque of 60 in. · oz, causing the arm to rise rapidly.
- When the arm gets up to 10°, Error = $SP - PV$ = 30° – 10° = 20°
  $\text{Output}_P = K_P E$ = 2 in. · oz/deg × 20° = 40 in. · oz
  - The motor torque has now reduced to 40 in. · oz, so the arm will slow down.
- When the arm gets up to 25°, Error = $SP - PV$ = 30° – 25° = 5°
  $\text{Output}_P = K_P E$ = 2 in. · oz/deg × 5° = 10 in. · oz
  - With a motor torque of only 10 in. · oz, the arm is slowing way down.
- Finally, when the arm reaches the new set point of 30°, Error = $SP - PV$ = 30° – 30° = 0°
  $\text{Output}_P = K_P E$ = 2 in. · oz/deg × 0° = 0 in. · oz
  - With the motor torque at 0 in. · oz, the arm stops.

Proportional Controllers: Problem

- Later, if the motor were directed to return to 0°, a new negative error would appear, causing a new (negative) motor torque to be generated:

  Error = $SP - PV$ = 0° – 30° = –30°

  $\text{Output}_P = K_P E$ = 2 in. · oz/deg × –30° = –60 in. · oz

- The negative sign of the output would result in a change in polarity of the applied voltage to the motor, which would cause it to run in the opposite direction.
- Thus, proportional control is capable of driving the arm in either direction.

Proportional Controllers: **Steady-State-Error Problem**

- Proportional control is simple, and is the basis of most control systems,
- But it has one fundamental problem—steady-state error.
- In practical systems, proportional control cannot drive the controlled variable to zero error because as the load gets close to the desired position, the correcting force drops to near zero.
- This small force may not be enough to overcome friction, and the load comes to a stop just short of the mark.
- Note: Friction, *always present in mechanical systems.*