

# Exhibit 2009

# Automatic Control Systems

*fifth edition*

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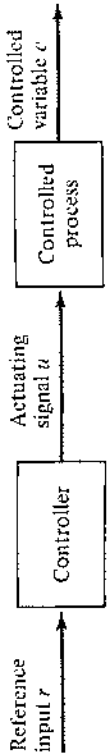


Figure 1-3 Elements of an open-loop control system.

The elements of an open-loop control system can usually be divided into two parts: the controller and the controlled process, as shown by the block diagram in Fig. 1-3. An input signal or command  $r$  is applied to the controller, whose output acts as the actuating signal  $u$ ; the actuating signal then controls the controlled process so that the controlled variable  $c$  will perform according to some prescribed standards.

In simple cases, the controller can be an amplifier, mechanical linkages, or other control means, depending on the nature of the system. In more sophisticated electronics control, the controller can be an electronic computer, such as a microprocessor.

### Closed-Loop Control Systems (Feedback Control Systems)

What is missing in the open-loop control system for more accurate and more adaptive control is a link or feedback from the output to the input of the system. To obtain more accurate control, the controlled signal  $c(t)$  should be fed back and compared with the reference input, and an actuating signal proportional to the difference of the input and the output must be sent through the system to correct the error. A system with one or more feedback paths such as that just described is called a *closed-loop system*.

The block diagram of a closed-loop idle-speed control system is shown in Fig. 1-4. The reference input  $\omega_r$  sets the desired idling speed. Ordinarily, when the load torque is zero, the engine speed at idle should agree with the reference value  $\omega_r$ , and any difference between the actual speed and the desired speed caused by any disturbance such as the load torque  $T_L$  is sensed by the speed transducer and the

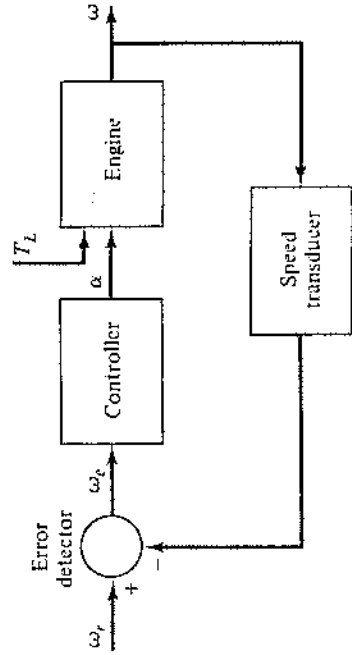


Figure 1-4 Closed-loop idle-speed control system.

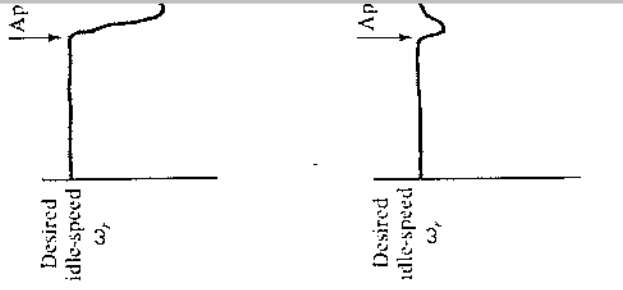


Figure 1-5 (a) Typical idle-speed response of an open-loop system. (b) Typical idle-speed response of a closed-loop system.

error detector, and the controller will operate on the difference to adjust the throttle angle  $\alpha$  to correct the error.

Figure 1-5 illustrates a comparison of the typical open-loop and closed-loop idle-speed control systems. In Fig. 1-5(a) the open-loop system will drop and settle at a lower value than the desired speed. In Fig. 1-5(b) the closed-loop system will drop and settle at the preset value after the application of  $T_L$ .

The idle-speed control system illustrated above is a system whose objective is to maintain the system output at a desired value. As another illustrative example of a closed-loop control system, consider the block diagram of the printwheel control system of a typewriter. The printwheel, which typically has 96 or 100 positions, is used to position the desired character in front of the hammer. When a key on the keyboard is depressed, a command for the printwheel position to the next position is initiated. The microprocessor

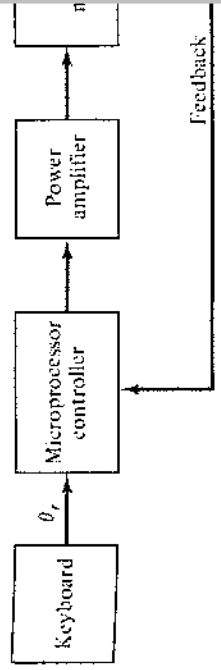


Figure 1-6 Printwheel control system.