Control Systems Engineering

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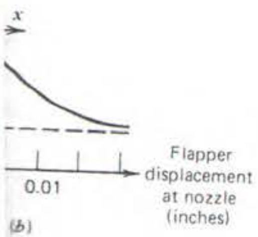

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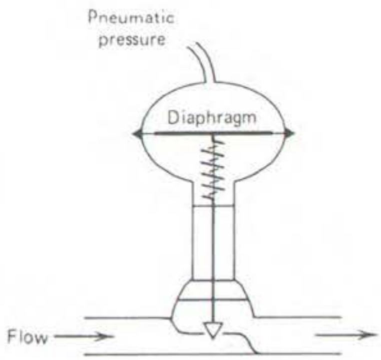

FIGURE 6.25 Pneumatic flow control valve.

can be used to drive a final control element like the pneumatic actuating valve shown in Figure 6.25. The pneumatic pressure acts on the upper side of the diaphragm and is opposed by the return spring.

The nozzle flapper is a *force distance* type of actuator, because its input is a displacement and its output a force (pressure). The other type of pneumatic actuator is the *force balance* type, in which both the input and output are pressures. The pressures are made to act across diaphragms whose resulting motion activates a pneumatic relay. Details can be found in the specialized literature (e.g., Reference 7).

6.5 CONTROL LAWS

The control logic elements are designed to act on the actuating (error) signal to produce the control signal. The algorithm that is physically implemented for this purpose is the *control law* or *control action*. A non zero error signal results from either a change in command or a disturbance. The general function of the controller is to keep the controlled variable near its desired value when these occur. More specifically, the control objectives might be stated as follows:

1. Minimize the steady-state error.
2. Minimize the settling time.
3. Achieve other transient specifications, such as minimizing the maximum overshoot.

In practice, the design specifications for a controller are more detailed. For example, the bandwidth might also be specified along with a safety margin for stability. We never know the numerical values of the system's parameters with true certainty, and some controller designs can be more sensitive to such parameter uncertainties than other designs. So a parameter sensitivity specification might also be included. We will return to this topic later, but for now, a general understanding of control objectives is sufficient for our purpose.

The following two control laws form the basis of many control systems.

Two-Position Control

Two-position control is the most familiar type perhaps because of its use in home thermostats. The control output takes on one of two values. With the *on–off* controller, the controller output is either on or off (fully open or fully closed). Such is the case with the thermostat furnace system. The controller output is determined by

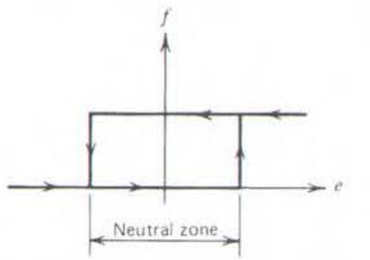

FIGURE 6.26 Transfer characteristics of the on–off controller. The actuating error is $e = r - c$, where r = set point, c = controlled variable, and f = control signal.

the magnitude of the error signal. The switching diagram for the on–off controller with hysteresis is shown in Figure 6.26.

An example of an application of an on–off controller to a liquid level system is shown in Figure 6.27*a*. The time response shown in Figure 6.27*b* with a solid line is for an ideal system in which the control valve acts instantaneously. The controlled variable cycles with an amplitude that depends on the width of the neutral zone or gap. This zone is provided to prevent frequent on–off switching, or *chattering*, which can shorten the life of the device. The cycling frequency also depends on the time constant of the controlled process and the magnitude of the control signal.

In a real system, as opposed to ideal, the sensor and control valve will not respond instantaneously, but have their own time constants. The valve will not close at the instant the height reaches the desired level. There will be some delay during which flow continues into the tank. The result is shown by the dotted line in Figure 6.27*b*. The opposite occurs when the valve is turned on. This unwanted effect can be reduced by decreasing the neutral zone, but the cycling frequency increases if this is done.

The overshoot and undershoot in on–off control will be acceptable only when the time constant of the process is large compared to the time lag of the control elements. This lag is related to the time constants of the elements as well as to their distance from the plant. If the control valve in Figure 6.27*a* is far upstream from the tank, a significant lag can exist between the time of control action and its effect on the plant. Another source of time lag is the capacitance of the controller itself. For example, if the heater capacitance in the temperature controller of Section 6.2 is appreciable, the heater will continue to deliver energy to the oven even after it has been turned off.

An example close to home demonstrates how the capacitance of the plant affects

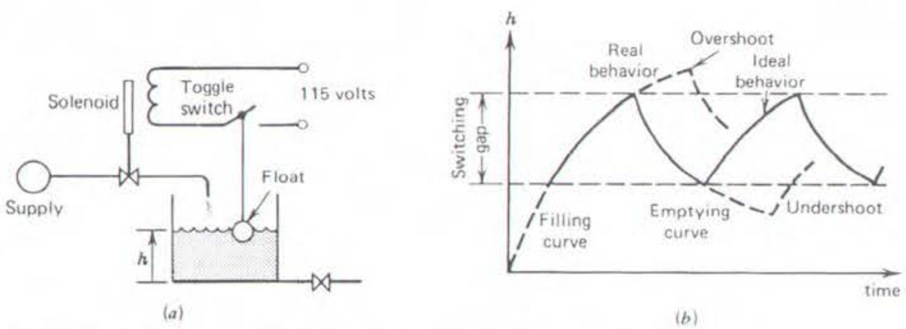

FIGURE 6.27 (*a*) Liquid level control with on–off action. (*b*) Time response.

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Proportional Control

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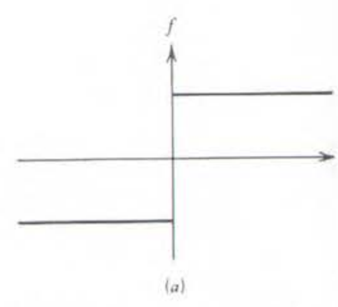

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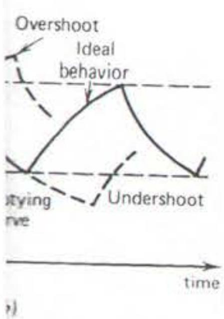

the suitability of on–off control. On–off control of the hot water valve in a shower will obviously be unsuitable, but it is acceptable for a bath, because the thermal capacitance is greater.

Another type of two-position control is the *bang–bang* controller whose switching diagram is shown in Figure 6.28*a*. This controller is distinguished from on–off control by the fact that the direction or sign of the control signal can have two values. A motor with constant torque that can reverse quickly might be modeled as a bang–bang device. Because such perfect switching is impossible, a more accurate model would include a dead zone (Figure 6.28*b*). When the error is within the zone, the controller output is zero.

Proportional Control

Two-position control is acceptable for many applications in which the requirements are not too severe. In the home heating application, the typical 2°F temperature gap is hardly detectable by the occupants. Thus, the system is acceptable. However, many situations require finer control.

Consider the tank system shown in Figure 6.27*a*. To replace the two-position controller, we might try setting the control valve manually to achieve a flow rate that balances the system at the desired level. We might then add a controller that adjusts this setting in proportion to the deviation of the level from the desired value. This is *proportional control*, the algorithm in which the change in the control signal is proportional to the error. Recall the convention that block diagrams for controllers are drawn in terms of the deviations from a zero-error equilibrium condition. Applying this convention to the general terminology in Figure 6.7, we see that proportional control is described by

$$F(s) = K_p E(s) \tag{6.5-1}$$

where $F(s)$ is the deviation in the control signal and K_p is the *proportional gain*. If the total valve displacement is $y(t)$ and the manually created displacement is x, then

$$y(t) = K_p e(t) + x$$

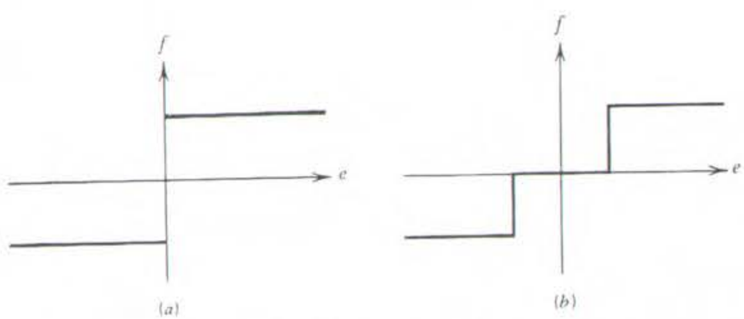

FIGURE 6.28 Transfer characteristics. (*a*) Ideal bang-bang control. (*b*) Bang-bang control with a dead zone. The control signal is *f*; the error signal is *e*.