System Dynamics and Control

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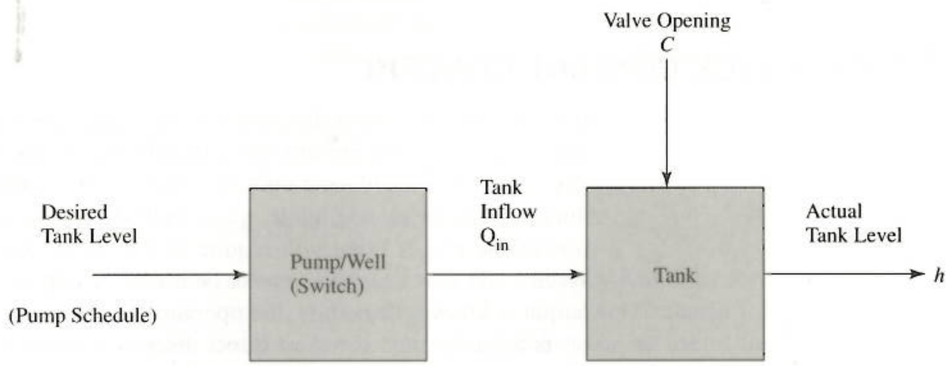
time the aggregate volume of water used at the various sites is fairly uniform and predictable, and that some variation in pressure and therefore performance can be tolerated in the applications, is to operate the pump and fill the tank from the well on some sort of time schedule.

Figure 1.4a shows the way the actual tank water level depends on the scheduled pump operation or the desired tank level. Although the pump operating schedule could have been deduced from, say, statistical analysis of past data on water use on the farm, there is nothing in the control scheme of Fig. 1.4a that prescribes any relationship between one variable of the tank and the other (the variables in this case being Q_{in} and h. The term Q_{out} is related to h through the valve opening parameter C, which is taken here as a perturbation of the system or a disturbance input). Indeed, if at any time the pattern of water use (equivalent valve opening) should deviate significantly from that on which the pump schedule is based, the control system could break down or perform very poorly. This type of control scheme is referred to as *open-loop control.*

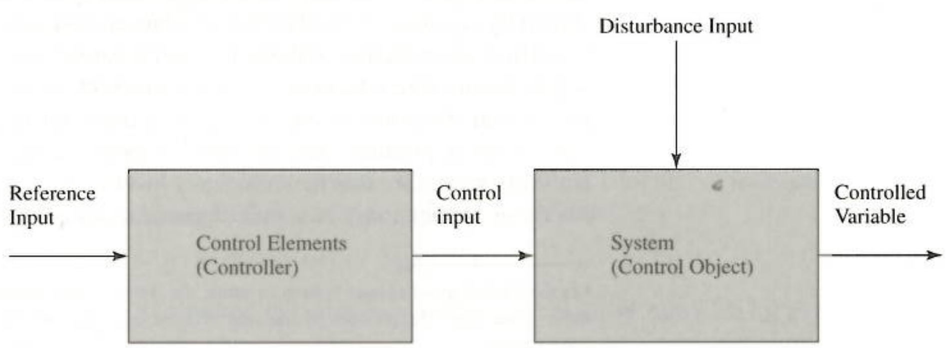
The structure of an open-loop control system is shown in Fig. 1.4b. The specific characteristic or variable of the system, the output, that we wish to control is referred to as the *controlled variable,* whereas the characteristic or variable that is determined by the control action is called the *control input.* The control elements can collectively be called the *controller,* although, as we shall see later, the control elements can be contained in other subgroups. The *reference input* generally implies the desired value of the controlled variable. In Fig. 1.4b the loop is open in the sense that there is no path through which the control input can be determined in terms of the controlled variable, that is, the controller does not prescribe a relationship between the control input and the controlled variable.

Figure 1.4

Open-loop Control of Water Supply System



(a) Simple Control Scheme for the Water Tank Level



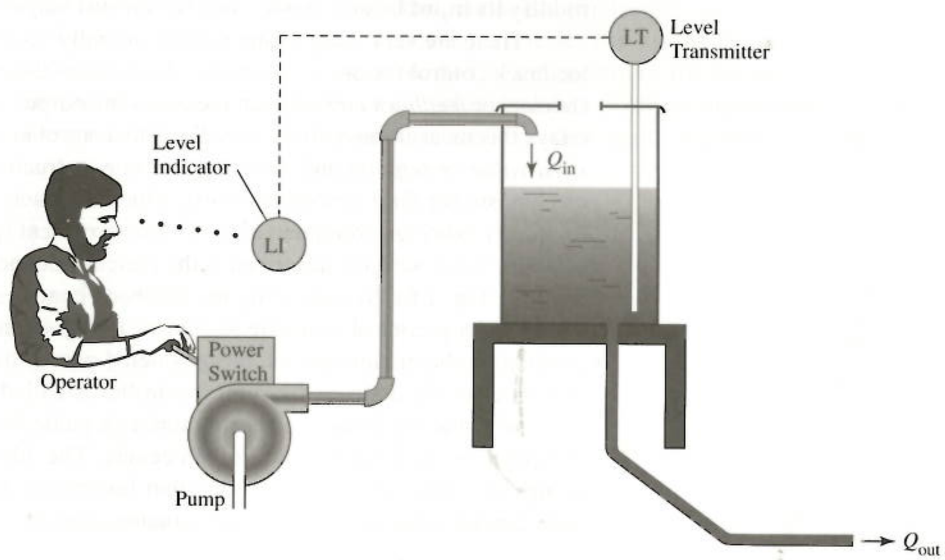
(b) Open-Loop Control Structure

Feedback Control Structure

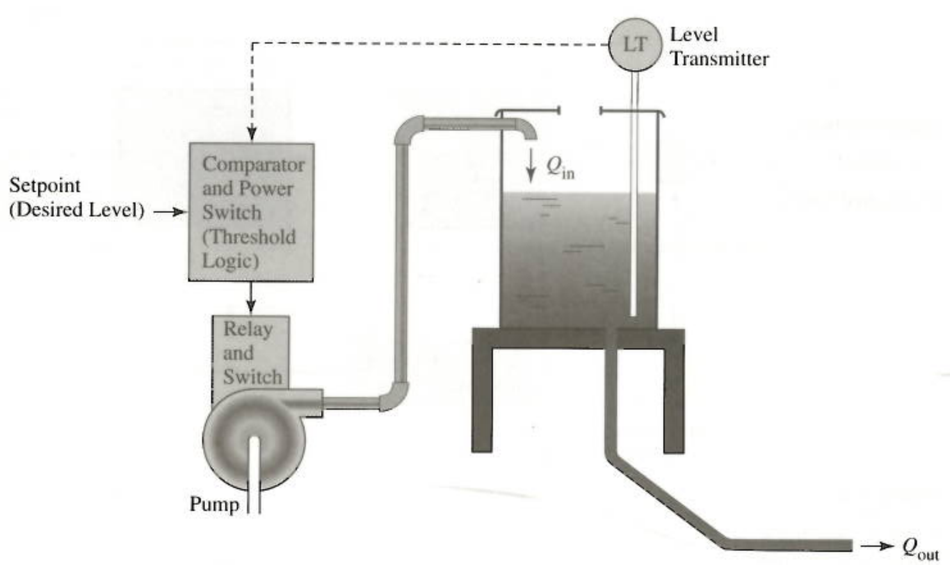
Another approach to the control of the water tank level is to have the pump operator turn the pump on whenever the tank water level drops below the reference value and to turn it off again when the tank fills beyond the reference level. To facilitate the work of the operator, a level measuring/transmitting and indicating system (LT and LI) can be connected to the tank and used to display the tank level at a location where it can conveniently be observed (see Fig. 1.5a). The result is a *closed-loop control* system, since there is a prescribed (albeit switching) relationship between the tank level and input flow. The operator observing the tank level provides the path that closes the loop. However, a control system with a human operator as an element of the controller is *manual,* that is, not automatic. On a busy farm or where it is not feasible to dedicate an employee to operation of the pump only, such manual control would clearly be in-

Figure 1.5

Manual and Automatic Control of Water Tank Level



(a) Manual Closed-Loop Control of Tank Level



(b) Automatic Closed-Loop Control of Tank Level adequate or unsatisfactory. An example of an *automatic* (closed-loop) control system for the tank level is shown in Fig. 1.5b. Here the comparison of the tank level signal with the desired value of the tank level (entered into the system as a setpoint setting) and the turning of the pump on or off are all performed by appropriate hardware in the controller. However, note that both the manual and automatic level control systems, just described, involve

1. the maintenance (in spite of external disturbances) of some prescribed relationship of one system variable to another using the result of a comparison of these variables;
2. the transmission of some signal or information from a later (output) stage to an earlier (input) stage of the system, that is, loop closure through *feedback*.

The concept involved here is that of *feedback control*.

In feedback control, a measurement of the output of the system is used to modify its input in such a way that the output stays near the desired value (see [2]).

There are very many systems both naturally occurring and man-made that rely on feedback control for proper operation. In all cases there is usually a sensory instrument *(sensor)* or *feedback element* that measures the output or system variable of interest and relays this measurement to a *controller*. The controller compares the signal with the *desired value* or *setpoint* and sends appropriate instructions to the *actuator* or "effector" mechanism (or *final control element*), which then acts on the system or *control object* (or *plant*) to bring subsequent outputs into agreement (prescribed relationship) with the setpoint. What we have described is the typical feedback (or closed-loop) control structure (see Fig. 1.6). In comparing the feedback control structure shown in Fig. 1.6 with the open-loop control structure shown in Fig. 1.4b, note that the actuator could, depending on the circumstances, be considered part of the controller or part of the plant. The input to the actuator from the controller is called the *manipulated variable*.

With the feedback control structure as a guide, we can analyze systems suspected of operating as feedback control processes. The idea is to identify components or groups of components of the system that function as the various elements in the feedback control structure—controller, actuator, control object, and sensor—as well as to

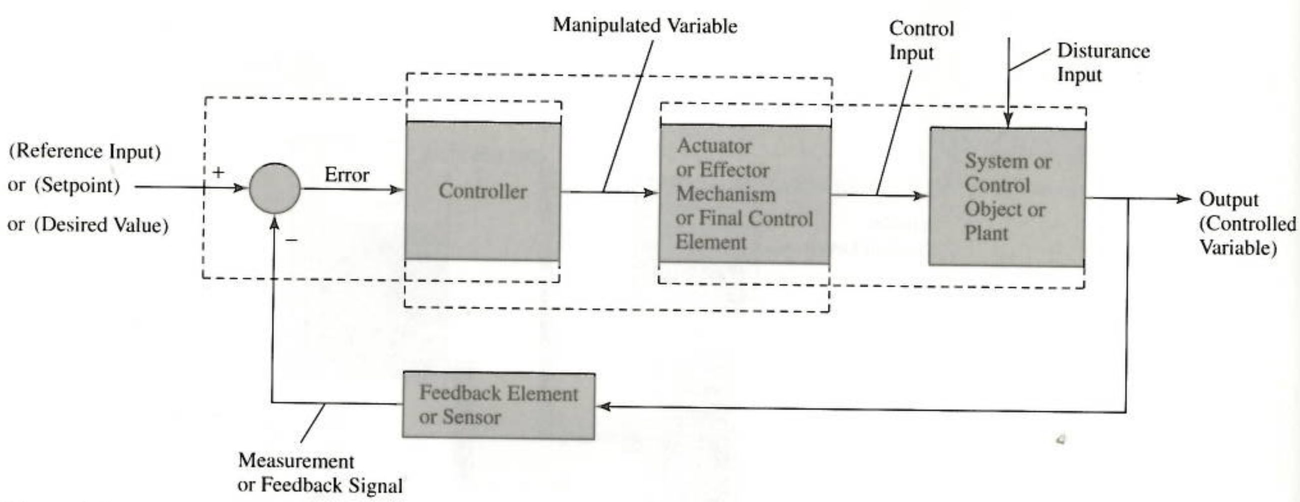


Figure 1.6

Typical Feedback Control Structure

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