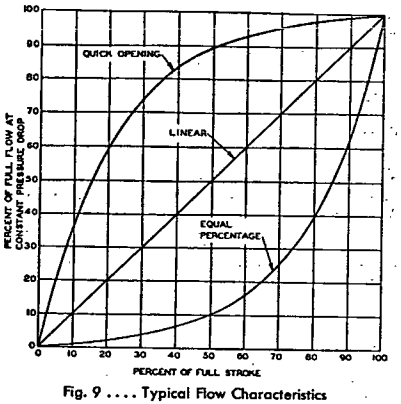

Fig. 9 .... Typical Flow Characteristics

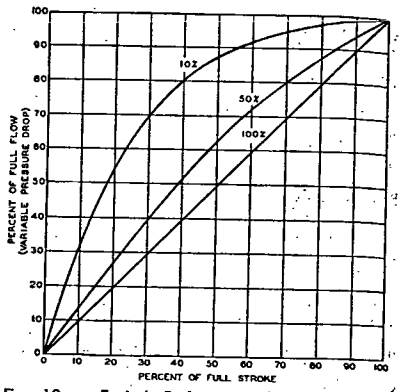

Fig. 10 .... Typical Performance Curves for Linear Devices Selected at Various Percentages of Total System Pressure Drop

that are adjusted for a horizontal air pattern. The diffuser in which the element is mounted should be in the center of the occupied area of the zone being controlled.

CONTROL OF FLOW

The successful operation of practically any air-conditioning system is dependent on the proper control of flow in one form or another. The flow being controlled may be steam, water, air, or some combination thereof. In each case, a controlled device is used to regulate the flow at the command of a controller. The proper design and sizing of these controlled devices (valves for steam or water, and dampers for air) are essential to obtain the desired results from the air-conditioning system.

The performance of a valve or damper is expressed by the control industry in terms of its flow characteristics as it operates through its stroke, based on a *constant pressure drop*. Three common characteristics are shown in Fig. 9 and may be defined as follows:

Quick Opening: Maximum flow is approached rapidly as the device begins to open.
Linear: Opening and flow are related in direct proportion.
Equal Percentage: Each equal increment of opening increases the flow by an equal percentage over the previous value.

Since the pressure drop across a valve or damper seldom remains constant as its opening changes, actual performance usually deviates from the published characteristic curve. The magnitude of the deviation is determined by the overall system design. For example, in a system arranged so that control valves or dampers can shut off all flow, the pressure drop across a controlled device increases from a minimum at design conditions to the total system pressure drop at no flow. Fig. 10 shows the extent of the resulting deviations for a valve or damper designed with a linear characteristic, when the selection is based on various percentages of the total system pressure drop. In order to approximate the designed characteristic of the valve or damper, the design pressure drop should be a reasonably large percentage of the total system pressure drop or the system should be designed and controlled in such a manner that this pressure drop remains relatively constant.

Higher pressure drops for controlled devices are obtained by using smaller sizes in conjunction with a possible increase in size of other equipment in the system. Since sizing techniques are different for steam, water, and air, each is discussed separately.

CONTROL OF STEAM FLOW

The size of an automatic steam valve is based on the required capacity at maximum load, under the conditions which will exist at that time. The equation for mass flow through an orifice or nozzle can be written as

$$w = CA\sqrt{P_1 - P_2} \qquad (1)$$

where

w = the flow of steam in pounds per hour.
A = the area of the port opening in square inches.
P_1 = the steam supply pressure, pounds per square inch, absolute.
P_2 = the downstream pressure, pounds per square inch, absolute.
C = a constant for a given steam supply pressure and a given valve body.

Valves for two-position operation usually are selected of a size adequate to supply the required maximum capacity with a reasonably low pressure drop ($P_1 - P_2$). It is necessary only to be sure that the valve will close against the system pressure and will have ample capacity when fully open.

Proportional valves for steam service must be carefully sized if stable control is to be achieved. Since, in general, the tendency is to oversize such valves, it should be remembered that no controller can produce its best results if handicapped by a valve which is too large. The function of the valve is to vary the value of area A in Equation 1, and it is desirable that the flow vary in proportion to the value of A. The correct maximum required capacity must first be determined.

There should be no factor of safety in this determination, and it should be based on actual heating requirements rather than on the condensing capacity of the coil, since the coil may be larger than necessary. It is also necessary to base the valve size on the actual supply pressure P_1 which will exist at the valve, since this supply pressure affects both the density of the steam and the pressure drop which will be selected.

Selecting the proper pressure drop ($P_1 - P_2$) across the valve when it is wide open and is supplying the maximum steam requirement is the most important consideration in determining the valve size. For purposes of discussion it will be assumed that P_1 is constant and that the valve is supplying steam to a heating coil which has air entering at a constant temperature and velocity. Any pressure drop between the valve and the coil will be neglected so that P_2 represents the pressure in the coil. The condensing capacity of the coil varies with changing values of P_2. When the valve is fully open, P_2 assumes a value such that the capacity of the valve and the condensing rate of the coil are in balance. If this value of P_2 is relatively large, then, as the valve is partially closed, P_2 will decrease until the capacity of the valve and the condensing rate of the coil are again in balance. Reducing the value of A in Equation 1 results in an increase in the value of $\sqrt{P_1 - P_2}$ and partially offsets the effect of closing the valve. This effect is greatest when P_2 is nearly equal to P_1 and diminishes as P_2 decreases.

The minimum value which P_2 can assume is established by the return line pressure (or vacuum) of the system. However, P_2 may reach a value which results in the critical velocity through the valve before it has been reduced to its minimum value. If so, any reduction of P_2 beyond this value has no further effect on the valve capacity. The critical velocity exists when P_2 is approximately 58 percent of P_1. The undesirable effect caused by variations in P_2 can be eliminated by selecting a valve size such that P_2 is at or near its minimum value, or the value corresponding to the critical velocity, whichever is higher, when the valve is wide open.

On low-pressure steam applications it is good practice to base the valve size on a pressure differential equal to 75 or 100 percent of the gage supply pressure. When the supply pressure is high enough so P_2 at the critical velocity (58 percent of P_1) is above atmospheric pressure, the valve size can be based on a pressure differential of 42 percent of P_1 absolute. All valves of the same size do not have the same capacity for a given pressure differential. Having established the supply pressure and the pressure differential, the valve manufacturer's tables or charts should be consulted in selecting the proper size of valve for the required capacity.

It is important that the supply pressure to an automatic steam valve be constant because it is difficult for a thermostat to produce stable results if the pressure is constantly changing. This situation arises, for example, when a steam boiler is operated by a two-position pressure controller. A pressure-reducing valve, which will supply a constant pressure to the steam mains while permitting the boiler pressure to fluctuate between the limits of the pressure controller, is recommended. Lacking this, the differential of the pressure controller should be set as narrow as is consistent with efficient boiler and burner operation. On vacuum return systems the vacuum pump also should operate on a narrow differential.

The use of two automatic control valves in parallel will often provide more stable control than a single larger valve, especially on large coils or steam-to-water heat exchangers. The valves should be sized so that one valve handles about one-third of the total capacity and the other about two-thirds. They are controlled in sequence so that the small valve operates during periods of light load and the large valve begins to open only after the load exceeds the capacity of the small valve.

The steam piping from the valve to the coil inlet, and from the outlet to the trap, should be the full size of the coil tapping or the size specified by the manufacturer of the coil, and should conform to recommended practice, as illustrated in Chapter 8 of the 1964 Guide And Data Book. It is very important that condensate be promptly drained from the coil. When the coil is at reduced pressure, as it will be much of the time, there will not be sufficient difference in pressure between the coil and the return line to obtain any lifting of the condensate.

CONTROL OF WATER FLOW

The capacity of a proportional valve for water service is not influenced by the supply water pressure, but only by the pressure differential. This is so because water is incompressible and because the inlet pressure is not an important factor in the thermal capacity of a water system. If a certain water circuit has a total resistance of 30 psi at maximum flow, of which 1 psi is through the valve, the resistance of the rest of the circuit is 29 psi. As the valve closes and flow is stopped, the resistance across the valve becomes the entire 30 psi. Therefore, the pressure drop across the valve increased by a ratio of 30:1 as the valve travelled from full open to full closed position. This increase in pressure drop as the valve is closed partially offsets the effect of closing the valve.

It is obviously impracticable to design a water system so that there will be no increase in pressure drop across the valve as it closes. However, it is important to design the system, including the valve, in such a manner that the ratio of this increase in pressure drop as the valve closes is kept as low as possible. Thus, if the design pressure drop across the valve is 5 psi instead of 1 psi, the ratio of increase is only 6:1 instead of 30:1, and the performance of the valve will be improved accordingly. This discussion assumes a circuit in which the entire flow is controlled by a single valve. The same reasoning will apply to the more complicated systems involving a multiplicity of parallel circuits, each having a valve. In general, it can be said that the pressure drop across a water valve at full flow should be a reasonable percentage of the resistance of the circuit in which the valve controls the flow. Due consideration should be given to any resultant increase in pumping head and operating costs.

As water circuits are subject to variable pressures in accordance with the pressure versus flow characteristic of the pump and changes in friction loss in the system as the flow varies, it is desirable to provide some means of system pressure control. Three general methods of control can be used to compensate for this pressure change. One is to maintain the flow in both the supply and return mains as constant as possible by installing a control valve in a bypass between the supply and return. The second method is to install an automatic control valve, in series with the pump, which closes as the flow demand of the system decreases. The third method is to apply a variable speed drive to the pump, since the pressure differential developed by a centrifugal pump is directly proportional to its speed. The location of the automatic control pressure-sensing device depends upon the system design and layout. The pressure-sensing point would usually be well out in the system, to get the best possible compromise in pressure variations at the individual unit valves. The bypass control valve can also best be located out in the water circuit. An automatic control valve in series with the pump would be located between the pump and the first branch circuit. Pressure control should be used on both hot and chilled water systems.