Flow Characteristics

Introduction

Flow characteristics, the relationship between flow coefficient and valve stroke, has been a subject of considerable debate. Many valve types, such as butterfly, eccentric disk and ball valves, have an inherent characteristic which cannot be changed (except with characterizable positioner cams). Flow characteristics of globe valves, such as the Mark One and Two, can be determined by the shape of the plug head.

The three most common types of flow characteristics are quick opening, equal percentage and linear. Figure 9-1 shows the ideal characteristic curve for each. These characteristics can be approximated by contouring the plug. However, inasmuch as there are body effects and other uncontrollable factors, plus the need for maximizing the flow capacity for a particular valve, the real curves often deviate considerably from these ideals.

When a constant pressure drop is maintained across the valve, the characteristic of the valve alone controls the flow; this characteristic is referred to as the "inherent flow characteristic." "Installed characteristics" include both the valve and pipeline effects. The difference can best be understood by examining an entire system.

Below is a brief synopsis of each of the three flow characteristics:

Equal Percentage

Equal percentage is the characteristic most commonly used in process control. The change in flow per unit of valve stroke is directly proportional to the flow occurring just before the change is made. While the flow characteristic of the valve itself may be equal percentage, most control loops will produce an installed characteristic approaching linear when the overall system pressure drop is large relative to that across the valve.

Linear

An inherently linear characteristic produces equal changes in flow per unit of valve stroke regardless of plug position. Linear plugs are used on those systems where the valve pressure drop is a major portion of the total system pressure drop.

Quick Open

Quick open plugs are used for on-off applications designed to produce maximum flow quickly.

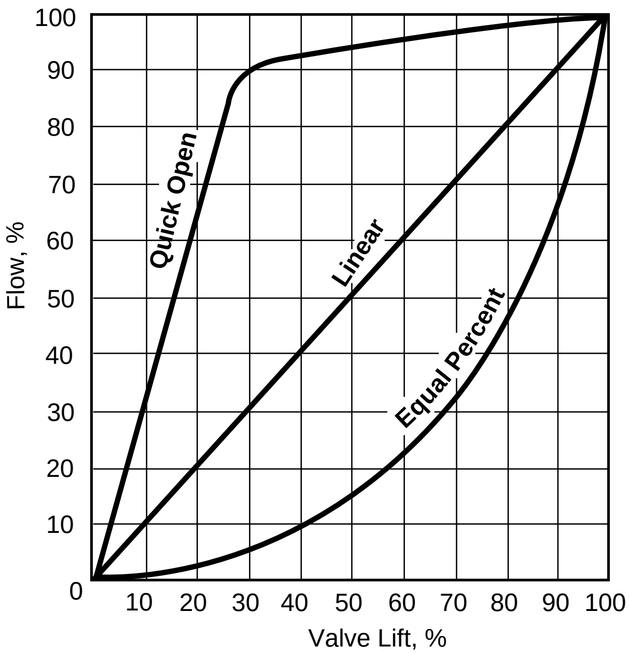

Figure 9-1: Inherent Flow Curves for Various Valve Plugs

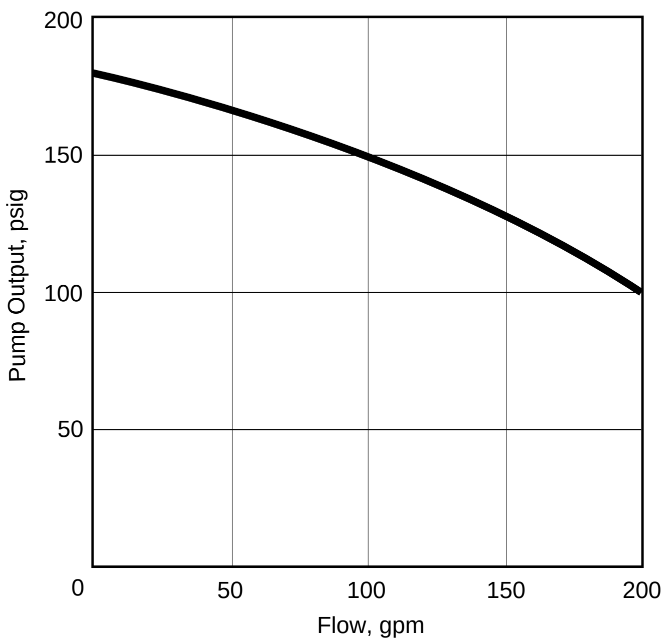

Figure 9-2: Typical Pump Characteristics

Example A

A centrifugal pump supplies water to a system in which a control valve is used to maintain the downstream pressure at 80 psig. The pump characteristics are shown in figure 9-2 and the schematic of the flow system is shown in Figure 9-3.

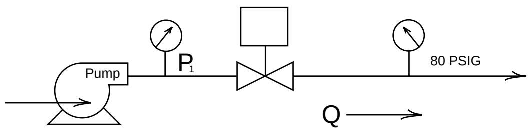

Figure 9-3: Flow Schematic Without Piping Losses

The maximum flow required is 200 gpm. at which the pump discharge pressure (P_1) is 100 psig. Piping losses are negligible. Using the ISA liquid sizing formula, the flow coefficient, or C_V, can be determined:

$$C_v = \frac{Q\sqrt{G_f}}{(F_p F_R)\sqrt{DP}} = \frac{200\sqrt{1}}{(1)\,(1)\sqrt{20}} = 45$$

The piping geometry factor, F_P, and the Reynolds number factor, F_R, are both assumed to have a value of one. A 2-inch Valtek Mark One control valve would handle the above application.

To determine the plug characteristic which should be specified, let us analyze the installed flow characteristic of "equal percentage" and "linear" trim in this 2-inch valve.

Based on the typical pump characteristic in Figure 9-2, Table 9-I shows several values of flow, the required valve C_V, and the percent of the maximum C_V which the valve must have to control the flow.

Table 9-I: Valve C_V and Pressure as a Function of Flow Rate, Without Line Losses

Q Flow gpm	P_1 Pump Discharge Press. psig	ΔP Across Valve, psi	C_V Required	% of Valve Max. C_V
200	100	20	45*	100
150	125	45	22	49
100	150	70	12	27
50	170	90	5.2	11

*C_V 45 is assumed to be the maximum C_V.

The percentage of total valve lift for equal percentage and linear plugs can be determined using Figure 9-1. The "installed characteristics" plotted as valve lift vs. flow in gpm, are shown in Figure 9-4.

Note that the installed linear characteristic is "pulled" toward the inherent quick open curve and the installed equal percentage curve is "pulled" toward the inherent linear curve. A study of Figure 9-4 shows that either installed characteristic will provide good control for this situation.

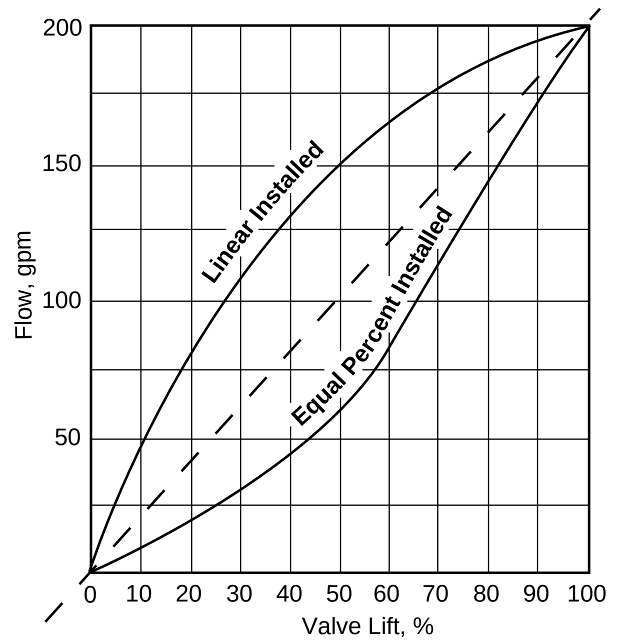

Figure 9-4: Installed Characteristics Without Piping Losses

Example B

The previous example was idealized in that the downstream pressure was held constant and the pressure drop variation was due to the pump characteristic alone. Now consider a more realistic installation where the delivered pressure must be held constant after passing through the valve and with some line restriction, R, in series with the valve. Schematically it would appear as illustrated in Figure 9-5.

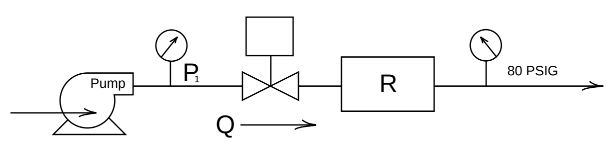

Figure 9-5: Flow Schematic With Piping Losses

To find the installed characteristics of equal percent and linear trim in a suitably sized valve, a pressure drop distribution must be chosen. A suitable choice would be 4 psi across the valve at a flow of 200 gpm. The control valve can then be sized for the maximum required C_V:

$$C_V = \frac{Q\sqrt{G_f}}{\sqrt{P}} = \frac{200\sqrt{1}}{\sqrt{4}} = 100$$

A 3-inch Valtek Mark One control valve would be chosen to handle these maximum flow condition.

Since the pressure drop across the restriction will vary with flow in accordance with the square root law ($Q = R\sqrt{\Delta P}$) the available pressure drop across the valve at various flowing quantities can be determined, keeping in mind the pump characteristic. This is shown in Table 9-II. As before, the percent of maximum C_V which the valve must have to control the flow is calculated and the "installed characteristic" is plotted as Figure 9-6.

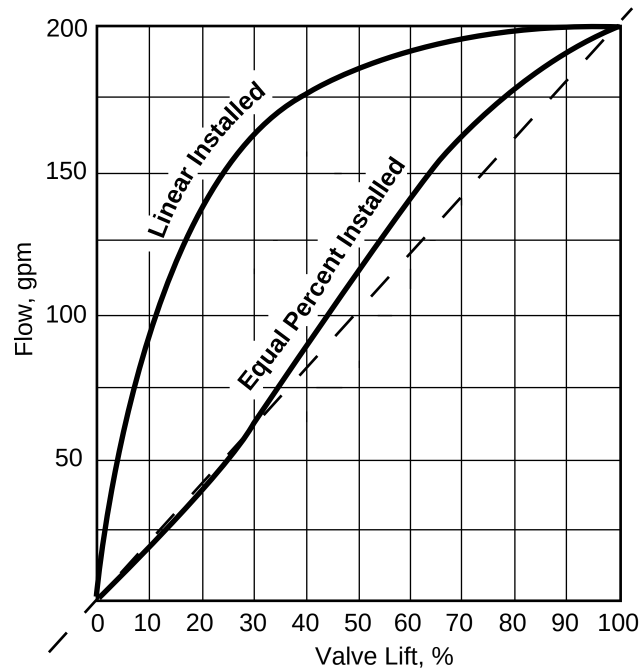

Table 9-6: Installed Characteristics With Piping Losses

Table 9-II: Valve C_V Pressure as a Function of Flow Rate With Line Losses

Q Flow gpm	P_1 Pump Discharge Press. psig	ΔP_R Across R	ΔP Across Valve	C_V Required	% of Required Max. Valve C_V
200	100	16	4	100*	100
150	125	9	36	25	25
100	150	4	66	12	12
50	170	1	89	5	5

*C_V 100 is assumed to be the maximum C_V.

Note the inherent equal percentage trim exhibits a nearly linear installed characteristic, while the inherent linear trim appears to be almost quick opening installed. Let us examine these curves from the standpoint of proportional band, considering the operating region from 50 to 150 gpm at low flows. It can be seen that for a given flow change, a very small change in lift is required for the linear trim as compared with the equal percentage trim. Thus, the sensitivity of the system is high.

Operating in the higher flow region, the opposite is true. That is, a larger change in lift (or instrument air output) is required for the same change in flow as the linear trim. Consequently, overall sensitivity will be decreased. The equal percentage trim would exhibit an almost constant sensitivity over the entire operating range. Therefore, one proportional band setting in the controller would be adequate for the equal percentage trim, whereas several would be necessary for linear trim.

Finally, a judgement can be made as to whether a linear characteristic or an equal percentage characteristic should be chosen. As a general rule, if the valve is the primary pressure loss mechanism and the inlet pressure is constant, the linear characteristic should be chosen. Such a system (having very little system pressure loss and/or inlet pressure increase with flow decrease) is unusual. On the other hand, if pipe and fitting resistance are major factors in the system, equal percentage would be the appropriate choice (such is the case in the majority of applications).

In actual practice, control instruments can be adjusted to handle normally anticipated flow changes without having to be readjusted. One would ordinarily have a difficult time telling, form control performance, whether the valve has linear or equal percentage trim unless manual control is required, then there will be a tremendous difference.