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## Guidelines for Selection of Liquid Level Control Equipment

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# Guidelines for Selection of Liquid Level Control Equipment

The factors which influence selection of equipment for a liquid level control loop interact significantly. Analyses of these factors and their interactions have resulted in a helpful set of equipment selection guidelines. The guidelines, which are presented in this paper, are based on the criterion that the level control system be stable with a gain margin of 2.25.

A word of caution, however. Some system performance problems which arise in practice do not necessarily respond to application of these guidelines. For example, a level system may cycle or behave erratically if: 1) The input or output flow rate cycles; 2) A high input flow rate causes severe turbulence; 3) A vortex forms in the vessel because of a large output flow rate; 4) Large quantities of condensate form and randomly increment the stored volume in the vessel; or 5) The liquid vaporizes, forming bubbles which alter the relationship between level and stored liquid volume.

The solution of these problems lies in the design of the process itself—process piping, heat exchangers, baffles, vessel inlets and outlets, and other process equipment—and is beyond the scope of this guide.

Assuming that the process and the process equipment have been properly designed, this guide summarizes recommendations which should assure closed loop stability. These recommendations will cover the selection of valve, controller, actuator, sensor, and vessel area.

## Valve Selection Considerations

The two most important considerations in valve selection are the valve size and the valve characteristic. It is important for good system performance that the valve not be oversized. It is recommended that the valve be sized for about 110 percent of the maximum expected process throughput. Guidelines for selecting valve characteristics are given in the Fisher Valve Sizing Catalog 10. These indicate that the proper valve characteristic usually will be linear. An equal-percentage valve characteristic is preferred only where the process throughput varies over a wide range of values and the valve pressure drop at maximum throughput is less than 20 percent of valve pressure drop at minimum throughput.

The only other property of the valve which is pertinent to control system stability is the amount of dead band present in the actuator-valve combination. It is theoretically impossible to achieve a stable level control system if dead band exists and if integral action (reset) is employed. If the dead band is due to friction, a positioner will solve the problem provided the positioner dynamics are appreciably faster than the control system dynamics. If the dead band is due to linkage backlash outside of the positioner loop, applying a positioner will not solve the problem completely, but applying a bias spring force to "take up" the backlash, or a vernier valve in parallel with the main control valve can solve the problem. It is recommended that a positioner always be used in liquid level control systems unless actuator size is so large that the positioner-actuator response is about as slow as the system. In this case a volume booster relay is recommended.

To achieve desirable system performance, the controller dynamics should always be faster than the system. Using a positioner or a booster assures that the volume load on the controller is small, and therefore, the controller is fast.

## Use of Integral Action

The selection of integral action as one of the controller modes has two important results: It reduces the steady-state error in level to nearly zero, but it increases the difficulty of achieving a stable system. Integral action should be specified if the level must be limited to a range of values which is less than 25 percent of the sensor span. After a flow disturbance, the integral action will return the level to the set point when steady-state conditions have been achieved. For acceptable system stability, slow integral action is required in liquid level systems. An appreciable time is therefore required to achieve steady-state conditions. Another possible problem when applying integral action in liquid level control systems is "reset windup" which can occur during start-up or during large flow disturbances.

The use of integral action complicates setting the proportional band on the controller for acceptable stability, but still achieves small, steady-state error. If the proportional band setting is to be assumed and some other parameter, such as tank area, is to be determined, the assumed value should be small enough to allow for adjustment (tuning), and to compensate for possible errors caused by data uncertainties. There is no optimum value to assume for a proportional band setting, but 50 percent is reasonable.

## Selecting the Sensor and Tank

The type of sensor employed influences the relationship between controller settings and the tank area required. This interaction is displayed in the form of equations relating the surface area of the liquid to the proportional band setting, the maximum expected throughput, and the rated span of the sensor. The basic formula is given by:

$$A = K\frac{Q}{PB}\frac{M}{RS} \qquad (1)$$

In this discussion, the liquid surface area (A) is expressed in $ft^2$; while (PB) is the controller proportional band setting in percent.

The constant (K) is determined by the assumed gain margin of 2.25, by the dimensions chosen for the variables and parameters, and by the assumption that the correct valve characteristic has been selected (usually linear for liquid level systems). In the instance of flow measured in gpm and area in $ft^2$, K equals 6.02.

It is assumed that the valve is sized such that its maximum capacity is equal to the maximum process flow rate. If the valve is oversized, flow rate (Q) will increase; and then either A or PB must increase to satisfy Equation (1).

The rated span (RS) of the sensor is the level change, in inches, required to cause a full output change out of a transmitter or sensor. (For example, with a Fisher Type 249 utilizing a 14-inch displacer, RS is 14.

M represents the dynamic loop gain of the system evaluated at specific frequency, which is the critical frequency—that is, the frequency at which a system cycles. The value of M depends on the type of sensor, transmitter, controller, and positioner employed in the loop. Table 1 lists some typical values of M to be used in Equation (1).

*Table 1. M Values to be Used in Equation (1)*

| ACTUATOR-POSITIONER COMBINATION | TYPE 249 DISPLACEMENT SENSOR WITH DAMPING ORIFICE | |
|---|---|---|
| | 2 Ft Equalizing Arm | 5 Ft Equalizing Arm |
| 3582-657/30 | .76 | 1.11 |
| 3582-657/40 | .76 | 1.11 |
| 3582-657/50 | .76 | 1.11 |
| 3582-657/60 | .88 | 1.26 |
| 3582-657/70 | .95 | 1.26 |
| 3582-657/80 | 1.02 | 1.33 |
| 470/30 | .76 | 1.11 |
| 470/40 | .78 | 1.20 |
| 470/60 | .85 | 1.15 |
| 470/80 | .55 | .89 |

The reason M changes as the equalizing arm length changes is evident after examining Equation (2).

$$W_N = \sqrt{\frac{g}{L_2 + \left(\frac{A_2}{A_1}\right)L_1}}\ rad/sec \qquad (2)$$

where:

$W_V$ = Undamped natural frequency acceleration of gravity

g = Acceleration of gravity

$L_1$ = Length of equalizing arm

$L_2$ = Wetted length of displacer

$A_1$ = Area of equalizing line

$A_2$ = Area of annular space between displacer and cage wall.

This equation was derived in TM-7, “The Dynamics of Level and Pressure Control”. In general, the shorter $L_1$ is, the more stable and more responsive the system is.

Equation (1) is a guideline derived from a stability analysis of liquid level systems and is based on the assumption that level is within the range of the sensor. Therefore, the equation is not valid when disturbances exceed the sensor range, as might be expected during plant start up or shut down.

Of course, the extremes in level which can be tolerated depend upon the process. In one instance, the level control objective may be that the tank never overflow nor run dry. While in another, the level must be kept within inches of the set point to prevent damage to processing equipment, such as heat exchangers. Regardless of the allowable variance in level, a properly designed system accounts for the greatest disturbance that can occur.

## Controllability Index

A relatively simple check can be made to determine whether or not conventional equipment will provide suitable level control. By rearranging Equation (1), the factors related to the process can be separated from those related to control equipment.

$$Q/A = \frac{(PB)\ (RS)}{(6.02)\ (M)} \qquad (3)$$

To provide some significance to the Q/A ratio of Equation (3), the units gpm/$ft^2$ should be converted in in / sec:

$$\frac{(231\ in^3/gal)}{(60\ sec/min)(144\ in^2/ft^2)}\ \frac{Q}{A} = 0.027\ \frac{Q}{A}\frac{in}{\sec} \qquad (4)$$

Equation (4) indicates that if the process is uncontrolled, if the maximum throughput is Q gallons per minute, and if the tank area is A square feet, the level will change 0.027 Q/A inches each second.

Since a great many successful level control systems have a Q/A ratio of less than 4.5 in / sec, Equation (4) provides an “index of controllability” that proves useful to system designers, equipment suppliers, and process engineers, alike. For instance, the designer can first use Equation (1) to determine a tank size and then check the reasonableness of the size with Equation (4). The equipment supplier can use Equation (4) to properly select the required process equipment, while the process engineer can use Equation (1) to gauge the effect of a change in proportional band.

## Examples

To illustrate use of the guidelines, consider an example. Assume that a tank is to be sized for a system in which maximum expected throughput is 645 gpm. The vessel is to be pressurized at 100 psig. The control valve is to be on the outlet of the tank, with the downstream pressure approximately atmospheric. The liquid being processed has a specific gravity of one.

To meet the maximum expected throughput, a 2” cage-style globe valve with a linear flow characteristic is chosen. This valve, with a Cv = 65.3, provides a flow under the assumed conditions of 653 gpm, which is acceptable. A suitable valve positioner/actuator combination for the valve is the 3582-657/60.

Suppose the steady-state level must stay at some point ± one inch. This can be achieved by using a Type 249 with a 14” long displacer and a Type 4181 proportional plus reset controller. Since a 2-foot long liquid equalizing arm between tank and cage will be used, the value of M from table 1 is 0.88.

Arbitrarily choosing a proportional band setting of 50 percent to allow enough adjustment for adequate tuning of the controller, and substituting these values into Equation (1), the necessary liquid surface area can be calculated.

$$A = \frac{(6.02)(653)(.88)}{(50)(14)} = 4.94\,ft^2 \qquad (5)$$

Assuming that any baffles, tubing, etc. within the vessel have a cross-sectional area of two square feet, the tank area must be the sum of the liquid surface area and the equipment area.

$$A_{tank} = 4.94 + 2 = 6.94\,ft^2 \qquad (6)$$

The tank diameter then would be given by Equation (6).

$$d = \sqrt{\frac{4}{\pi} A_{tank}} = \sqrt{\frac{4}{\pi}\,(6.94)} = 2.97\,ft \qquad (7)$$

Equation (3) now should be used to check this answer by substituting 653 for Q and 4.94 for A. The solution shown in Equation (7) indicates that the equipment and tank size selected should provide stable control.

$$Ratio = (0.027)\frac{653}{4.94} = 3.53\,in/sec \qquad (8)$$

As a second example, a differential pressure sensor is used instead of a displacer. The sensor is calibrated for a span of 25 inches; and assume that M at maximum damping is 0.14. All other conditions remain as in the first example.

Substituting these values into Equation (1) yields the liquid surface area:

$$A = \frac{(6.02)\,(653)\,(0.14)}{(50)\,(25)} = 0.44\,ft^2 \qquad (9)$$

Again assuming two square feet for equipment within the tank, the tank area would be:

$$A_{tank} = 0.44 + 2 = 2.44\,ft^2 \qquad (10)$$

And the tank diameter again can be calculated.

$$d = \sqrt{\frac{4}{\pi}\,(2.44)} = 1.76\,ft \qquad (11)$$

Utilizing the controllability check provided by Equation (3), the Q/A ratio is found to be far greater than the desired 4.5 in/sec.

$$Ratio = (0.027)\ \frac{653}{0.44} = 39.7\,in/sec \qquad (12)$$

Although the system would be stable if the tank was extremely long, it still might not be controllable even if the definition of control meant keeping the level between safe and reasonable values.

Since the assumed control equipment included a differential pressure sensor with maximum damping, the dynamic response of the control equipment would be relatively slow, thereby intensifying skepticism about being able to control the system. This does not mean that differential pressure sensors should not be used for level control. It simply means that for this particular system, a larger surface area than that calculated should be employed.

Use of a larger surface area means there will be less of a level change when a change in load alters the net flow. It also allows use of a smaller proportional band setting, as shown by Equation (4). The smaller proportional band means the control valve strokes farther for a given change in level, the result being that the level is maintained closer to set point.

## Summary

A simple mathematical guide to stable liquid level control systems has been described which dictates that control components should be selected so that Equation (1) is satisfied. This guideline is easy to use and yet complete enough to assure confidence in the results obtained.

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