Instrumentation and Control - Course 136

CONTROL EQUIPMENT REVIEW

The equipment in a basic process control loop can be divided into three main categories:

1. The measuring Element.
2. Controllers
3. Final Control Element.

The measuring element will usually consist of a primary element (temperature or pressure measurement) coupled to a transmitter. This combination can be either pneumatic or electronic but, for the purposes of this course, we will consider only the electronic system. (The pneumatic system can be reviewed by reference to 430.31-1 and 430.31-2.) For pressure (also flow and level) measurement the primary element will have some form of position detector to produce final electronic signals of 4-20 mA from the applied force. This position detector will take the form of a variable resistive, capacitive or inductive element depending upon manufacturer.

The inductive detectors are generally of two types. One, a standard variable inductance, (Figure 1) as used by F&P and Honeywell and the other which takes the form of a variable mutual inductance, or Linear Variable Differential Transducer (LVDT), as used by Foxboro (Figure 2). Both types of inductive sensor will be operated from a frequency source of a few kilohertz. This ensures relative immunity from the effects of stray 60 Hz magnetic fields and also reduces the physical size of the inductive components.

Resistive elements, usually in the form of strain gauges, can be employed to produce a resistive change proportional to the applied force. These strain gauges are usually used in a Wheatstone Bridge configuration. A typical detector system as used by Statham-Gould is shown in Figure 3.

If the pressure capsule element is used to move the plates of a variable capacitor, the capactive reactance ($X_C = 1/2\pi fc$) can be made proportional to the applied pressure. This is the principle used in the Rosemount transmitter (Figure 4).

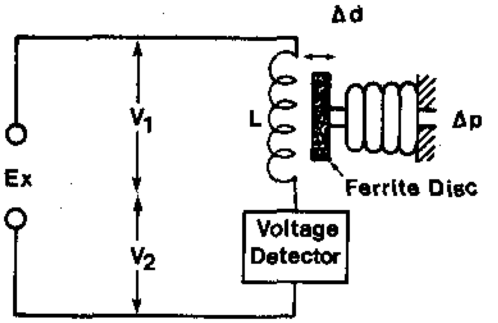

Figure 1: Inductive Sensor.

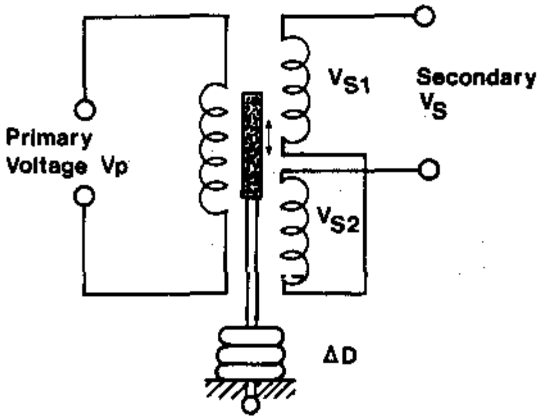

Figure 2: Linear Variable Differential Transformer.

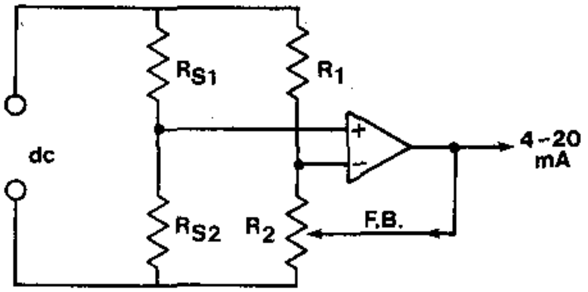

Figure 3: Resistive Sensor.

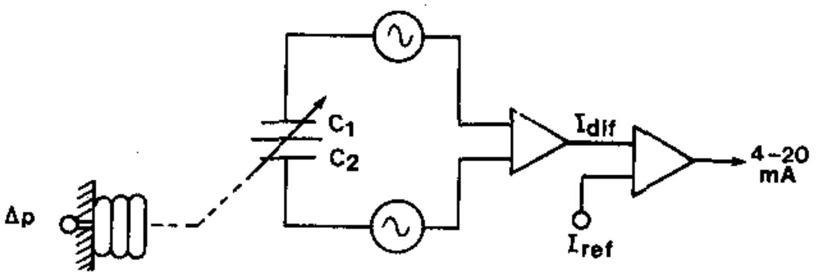

Figure 4: Capacitive Sensor.

It should be noted that all electronic transmitters will produce a 4-20 mA signal when used in the standard current loop configuration.

For temperature measurement the primary element in an electronic system will be either a thermocouple (TC) or a Resistance Temperature Detector (RTD). The thermocouple generates a millivolt level signal proportional to temperature and type of materials used as the hot junction. RTD's exhibit a resistance charge proportional to temperature. The RTD is usually incorporated as one arm in a Wheatstone Bridge configuration.

Controllers

The signal from an electronic transmitter will usually be fed to a controller. This will compare the signal with a predetermined setpoint to produce an error signal. The controller must be capable of changing the amplitude and direction of this signal in order to restore the controlled variable to its setpoint following a process variation. It will therefore have adjustable proportional and intergral modes as standard and derivative mode as an additional extra option. These features are usually achieved by using operational amplifiers and methods of obtaining these are shown in 336.2. A representative electronic controller is shown in Figure 5. The optimum settings of P, I and D will be discussed in a later lesson.

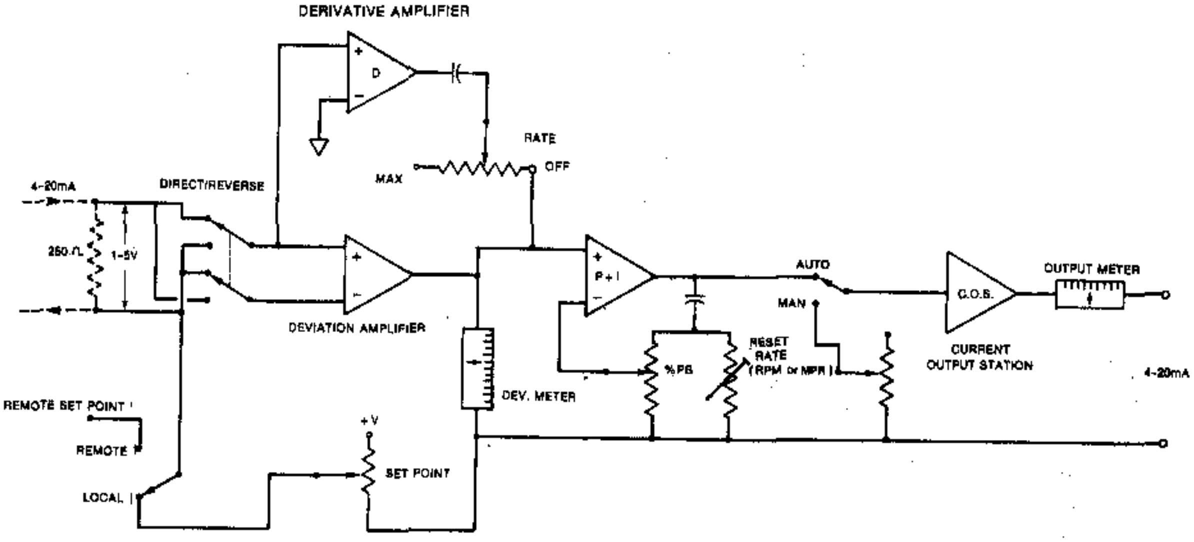

Figure 5: Representative Electronic Controller.

Note that it may also be necessary to incorporate other items of electronic equipment with the controller. These will include: high, low or median select circuitry, square root extractors, (when flow measurement is involved), and signal summing and averaging relays. In addition, high or low level alarms in the form of pressure switches or current alarms may be included. All these items are fully described in 230.30-4.

Final Control Element

We shall consider only the control valve as a final control element since it is by far the most widely used device. We will not consider the many and differing types of valves that exist but there are two important factors that require more detailed discussion. These are the flow capacity and flow characteristic of the valve.

Flow Capacity is the maximum volume of gas, liquid, or steam that may be passed through the valve in unit time with the valve fully open. This is more usually related to the flow coefficient (CV) which is defined as the volume of water (in US gallons) that will flow through the valve at maximum opening with a pressure drop, across the valve, of one psi.

The Basic Flow Equation is based upon the general equation:

$$Q = K\sqrt{\Delta p}$$

where Q is the flow rate, Δp is the pressure head across the orifice or valve and K is a constant. For valves the constant (K) is associated with the valve coefficient (CV).

$$Q = C_V\sqrt{\Delta p} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Now Δp is a measurement of head and must be converted to pressure.

$$\Delta p = sh$$

where, Δp = pressure
s = specific weight
h = head

$$\therefore h = \Delta p/s$$

substituting in equation (1)

$$Q = C_V\sqrt{\Delta p/s}$$

$$\text{or } C_V = Q\sqrt{s/\Delta p}$$

Valve Characteristics

Inherent Flow Characteristic of a valve is defined as the relationship between fractional valve lift and the relative flow through the valve at a constant pressure drop.

Installed Characteristic is the actual lift versus flow characteristic under system operating conditions and is unique to each specific installed system.

Most commerically available valves have inherent flow characteristics that fall between the quick opening and equal percentage curves as shown in Figure 7. These are based upon characteristics provided by the manufacturer and are determined by experimental methods.

The valve gain can be assessed from these curves and is equal to the slope of the characteristic. The linear valve has a constant gain of 1 while the equal percentage valve has a low gain at the near closed position that increases to a higher gain at full capacity. The quick opening valve provides essentially the opposite conditions.

If we consider a typical control loop diagram, Figure 6, we can illustrate the relationship of valve gain to controllability.

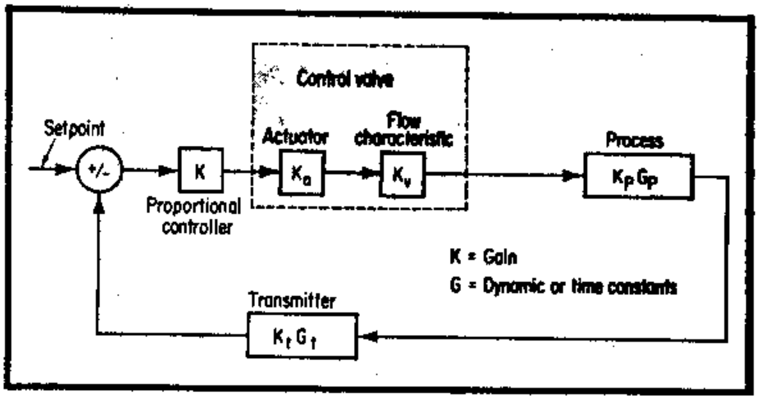

Figure 6: Representative Control Loop.

Ideally the open loop gain, K_L, of a stable control loop is constant and equal to:

$$K_L = K.K_a.K_v.K_p.K_t$$

where K, (controller gain) K_a (actuator gain) and K_t (transmitter gain) are almost constant over wide ranges of operation. Thus the process gain, K_p, and the valve gain, K_v, must compensate for each other if the loop is to remain stable and linear.

If these gains are not compensating it would be necessary to continually adjust the controller gain to correct the differences. Thus good design dictates that the valve must compensate for the changes in gain over as wide an operating range as possible. To match the gains by selecting the control valve characteristic can be accomplished relatively easily by considering the types of systems most often encountered.

Consider first the case where the control valve is throttling flow between a stable high pressure system and an almost constant lower pressure system with low frictional losses other than those of the valve itself, ie, the loop has a relatively constant process gain. A linear characteristic would be the obvious choice for this application. An example would be the feed valves in the Heat Transport System.

For a second example, consider a system with piping losses relatively higher than the pressure drop across the valve. This type of system is more repsonsive at low flows and more restricted at higher flows due to the increased frictional losses. The control valve should have a characteristic which compensates for the decay in process gain at high flows, ie, an equal percentage valve should be used. For a typical example consider the light water zone level control valve.

The quick opening valve is naturally used for applications where on/off type of control is required, eg, liquid poison injection for shut down System 2.

It must be remembered however that installed characteristics can be decidedly different from inherent characteristics, as supplied by the manufacturer, which were determined under laboratory conditions. The general form of typical flow characteristics is shown in Figure 7.

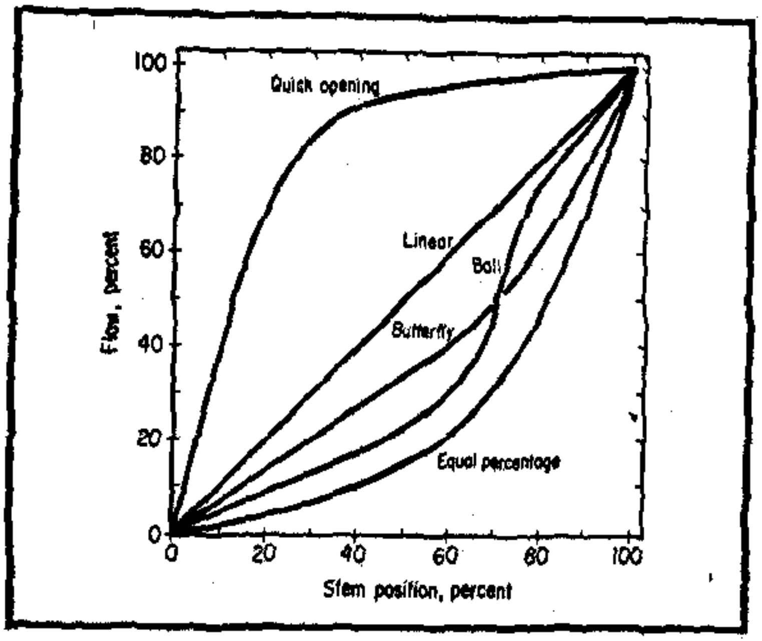

Figure 7: Typical Valve Flow Characteristics.

If a sufficiently high pressure drop can be allocated to the valve, then the installed characteristic would be very near the inherent characteristic. But as a lower valve pressure ratio is applied, the inherent characteristic will tend to linearize for an equal percentage valve and approach a quick-opening characteristic for a linear valve, ie, the flow versus travel, graphs move to the left. If this trend is continued all characteristics approach the quick opening and on/off curves which lead to unstable loop conditions and which will require frequent controller tuning to accommodate load changes. The design must therefore include sufficient pressure drop, say 10-30 percent of the system frictional losses in a pumped system, to maintain the required installed characteristic.

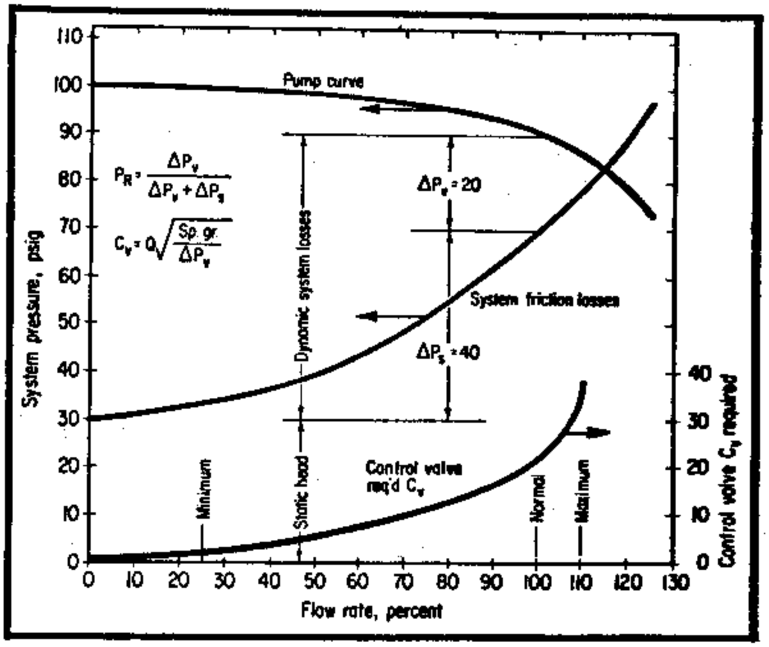

Figure 8: Typical Pump and System Curves.

Consider Figure 8 which shows a typical pump curve where head decays as flow increases. The frictional losses, P_s, increase with flow rate and are proportional to the square of the flow. The remaining element, static head, will be essentially constant for any particular system. Note that the pressure available for the control valve is represented by the difference between the pump head and the sum of the static head and dynamic losses. From the data available the curve of the installed characteristic for the ideal control valve for the system can be developed.

For the example above, it can be seen that at 100% flow the total dynamic system losses equal 60% of the system pressure, and 33% of the total system losses, (P_R), appear across the valve. C_v can be calculated and at 100% flow equals 22. The C_v is then calculated for varying flows and the control valve characteristic can be drawn. For the case illustrated above therefore an equal percentage valve of C_v approximately 50 would be a reasonable choice for a design flow of 100 % with maximum and minimum flows of 110% and 25%.

If the pressure drop for the valve was decreased to 10% of the system frictional losses, only 6 psi of the total system pressure would appear across the valve. This would allow a pump with a 14 psi lower head to be used to meet the same maximum flow conditions and a required C_v of approximately 40. Note that the design flow C_v has increased by approximately 100% because of the reduced pressure drop and the valve size would have to be increased to achieve the desired reduction in pump size. Remember that in the vast majority of systems an equal percentage value will be used, but in cases where the major system losses are in the control valve a linear characteristic should be selected.

Valve Actuators

Actuators are available in a wide range of forms, the common spring diaphragm actuator is, however, by far the most economical and widely used because of its simplicity and proven reliability. A control signal range of 20-100 kPag is usually selected to operate control valves. When the system is electronic, a transducer is therefore required to convert the 4-20 mA signal to a 20-100 kPa pneumatic signal for input to the valve.

Traditionally the nominal 5:1 signal range with live zero, has been utilized to allow the 0-20 kPa and 100-120 kPa regions to provide excess stem loading to assure tight shut off. It should be remembered that with electronic controllers and electronic/pneumatic transducers there will be little, if any, over-ranging capability to provide tight shut-off. This condition must be either allowed for when specifying the valve type, or by off-setting the shutoff at either end of the range and thereby limiting the signal span.

Dynamic Response

The speed of response of an actuator is determined by the volumes of the signal tubing and diaphragm housing. Valves over about three inches in body size with standard actuators will generally exhibit a slower response and a volume booster or positioner should be provided to overcome this problem.

A volume booster is a pneumatic relay that has a small volume at the inlet side and a high capacity regulator to provide a larger volume output signal. It is often 1:1, but can be 1:2 or 1:3. It will help to overcome lags caused by long signal tubing and large volume actuators.

The valve positioner is a valve mounted accessory that drives the control valve plug to the precise position requested by the input signal. In doing so it also overcomes hysterisis effects caused by packing friction, increases the speed of response, provides improved sensitivity, allows a signal reversal option and split ranged control.

Most positioners incorporate a by-pass switch which removes the positioner from the signal path between controller and valve actuator. This is sometimes necessary for maintenance purposes. Before operating the by-pass it is advisable to establish whether or not the positioner is being used in a reverse acting role, is providing amplification, or split ranging. Operating the by-pass switch under these conditions will cause loss of control.

Fail Safe Action

During the design of process loops, it is usual to consider each valve for failure positioning. This should be reviewed from two standpoints, one in the event of a total plant failure and secondly if a single valve loses its signal source.

Three choices are available:

1. Fail Open,
2. Fail Close,
3. Lock-Up In Last Position.

The first two options are usually achieved through selection of spring action that will drive the valve to its desired position when opposing power is lost. Lock-up is accomplished with a system of air reservoirs and valves. The spring technique is the most reliable and should be used if possible.

ASSIGNMENT

1. Describe the two types of inductive sensing elements used in the pressure transmitter. Why is the driving voltage at a frequency of a few kilohertz.

2. Sketch and label a typical representative electronic controller.

3. Define the flow co-efficient of a valve.

4. Describe a typical system in which a valve with the following flow characteristic could be used:

   (a) Linear,
   (b) Quick-Opening,
   (c) Equal-Percentage.

5. Why is it necessary to allocate a sufficiently high proportion of the total system pressure losses to a control valve (linear or equal percentage).

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