Principles of Automatic Control

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Automatic control instruments have a great deal in common with economic principles; they deal with supply and demand. Considering that an upset in a process is a change in demand, an automatic controller must be capable of changing the supply to re-establish process balance; therefore, automatic control may be defined as balancing supply against demand over some period of time. The period of time involved in making the supply equal to the demand may vary widely, and is primarily a function of process conditions.

Automatic control problems fall into two basic classifications; those requiring on-off control action and those requiring proportional or throttling control action. Between the two, there can be no general comparison as their use depends on process conditions.

There are various mediums for the operation of automatic mechanisms including hydraulic, pneumatic and electric, but by far the greatest majority of automatic controllers in industrial use are pneumatically operated, particularly in those applications requiring proportional action.

Automatic control can be applied to any process in which a measurement of the variables can be obtained. Some of the variables encountered in the field of measurement are pressure, temperature, flow, liquid level, humidity, specific gravity, pH, speed, force, load, torque, conductivity and consistency.

The function of the control mechanism in a pneumatically operated controller is to increase or decrease the air pressure to a second mechanism which in turn is regulating the controlling medium. The control mechanism in the automatic controller is actuated from a measuring system.

The mechanism which receives its air impulse from the automatic controller may operate a valve in a line of flowing fluid, a damper in an air duct, or it may actually change the control point setting of a second control mechanism. A complete automatic control system consists of three parts; the measuring unit, the automatic control unit and the control medium unit. The automatic control instrument itself is only a relay between the point of measurement and the point of regulation of the controlling medium. The effect of a change in the measured variable is transmitted by the measuring system to the control instrument which relays the effect of the change in measured variable in terms of an air pressure change to the mechanism which regulates the controlling medium through a control valve.

It has been stated previously that there are two basic types of automatic control action; on-off and proportional. Actually there is only one basic type as applied to process control, namely proportional. On-off is zero proportional action. On-off action is applicable primarily to single capacity batch processes having a reasonably high capacity-demand ratio. Although proportional action is the basic stabilizing action, it will not produce point control if the process is subject to load changes or changes in demand. It is necessary, therefore, to incorporate into a control mechanism with proportional action, a secondary action known as automatic reset. Automatic reset maintains point control regardless of load changes. A proportional mechanism is designed to produce a definite position on the valve for a position of the pen within the limits of the measurement scale range. The pen is positioned by a change in measurement. The valve is positioned by air pressure change. Figure X shows graphically the relation between measurement change or pen position and valve stroke. Curve A shows that the pen must change over the entire scale range to change the valve from fully open to

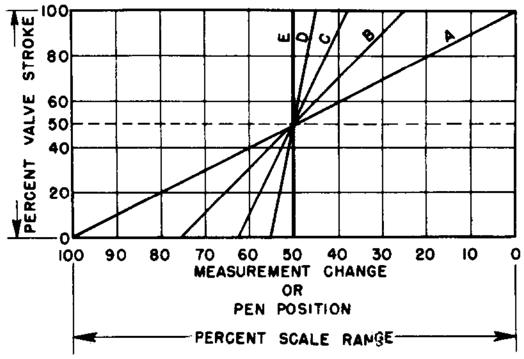

FIG. X

fully closed position. It also shows that for any position of the pen within the scale range, there is a corresponding position of the valve in terms of its stroke. For example, if the pen is at 20% of the scale range, the valve is at 80% of its stroke. If the pen is at 50% of the scale range, the valve is at 50% of its stroke, and if it is at 80% of the scale range, the valve is at 20% of its stroke. Because the pen must change 100% of the scale range to attain 100% valve stroke, the proportional action or proportional band is referred to as 100%.

Curve B shows that the pen position must change between 25% of the scale range and 75% of the scale range to attain 100% valve stroke. Curve B then represents a 50% proportional band. Curve C represents a 25% proportional band, Curve D a 10% proportional band, and Curve E represents zero proportional band or on-off control.

The fact that all of these curves intersect at 50% valve stroke and 50% scale range is significant only in the fundamental design of the proportioning mechanism. If the desired control point is at 50% of the scale range and the pen is at that position, then the valve is at 50% of its stroke regardless of which proportional band is in effect. If the control point were at 70% scale range and the pen were at that position, the curves would intersect at the 70% scale measurement and 50% valve stroke.

The curves show that as the proportional band is decreased, the valve stroke per increment of pen change is increased. Because of process conditions, ability to adjust the proportional band to different values is absolutely necessary in all automatic controllers requiring proportional action.

The following curves show the valve action corresponding to measurement change or pen motion for the various types of control action.

Fig. 1 shows the valve action produced by an on-off control mechanism when the measurement changes as indicated. Valve action occurs only as the measurement crosses the control point, and the valve operates from one extreme to the other. For all positions of the measurement above the control point, the valve has one position for all positions below the control point, the valve has another position.

The measurement of an on-off controller must be continually cyclic. When the amplitude of these cycles becomes excessive, the on-off action must be changed to a type which will produce a throttling valve action.

Figure 2 shows the relation between valve movement and measurement change of pen movement with proportional action. The difference between this and the on-off control action shown in Fig. 1 is at once apparent, as in Fig. 1 the valve moved intermittently, while in Fig. 2 the valve con-

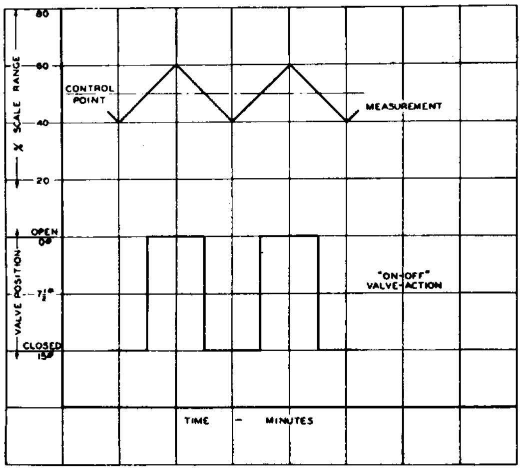

Fig. 1

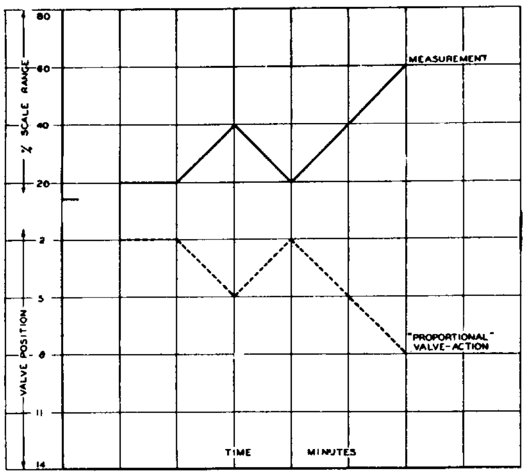

Fig. 2

tinues to move as long as the measurement is moving. At any time, the amount of valve movement is directly proportional to the amount of measurement movement. The valve position always bears a fixed relation to the measurement, and the maximum value in valve correction occurs at the point of greatest measurement deviation, as long as the measurement does not move outside the proportional band of the controller.

It is important to realize that with proportional action, each valve position is related to a definite position of the measurement. A controller may be adjusted so that the valve is positioned to bring the measurement to the control index, but the measurement will be maintained at this point only as long as there is no change in either load or other conditions. If there is a change in load or other condition such as pressure drop across the valve, then the valve must assume a new position in order to pass the original flow. Therefore, the measurement must move to a new position, which necessarily will be away from the control point before equilibrium is again reached. This "drift" from the control point with load or condition changes is defined as "offset" in A.S.M.E. terminology.

Where operating conditions and the proportional band of the controller are such that the maximum offset is within the permissible variations of the controlled medium, a proportional controller is satisfactory. When this condition is not satisfied, it becomes necessary to add a second function to the controller which establishes equilibrium at the control point setting regardless of the position of the valve required to restore this equilibrium. This function is known as automatic reset.

Reset action produces a valve position change at a rate proportional to the measurement deviation from the control point, and the amount of valve movement as a result of reset action is additive to the amount of valve movement produced by proportional action. The two actions are simultaneous. The valve movement from proportional action will increase or decrease only as the magnitude of the measurement deviation increases or decreases, whereas the valve movement from reset action will increase or decrease as the magnitude and duration of the measurement deviation is increased or decreased.

Figures 3 and 4 show valve action resulting from reset action only; that is, independent of proportional action. In Fig. 3, the pen position is changed abruptly an amount equivalent to (a) and maintained at the new value for a period of time. This measurement change or pen deviation is referred to as a fixed deviation, and this produces a constant rate of air pressure change on the valve as indicated by angle X. If the fixed deviation continued as shown for long enough period of time, reset action alone would increase the pressure on the valve at a constant rate until the maximum valve pressure was reached.

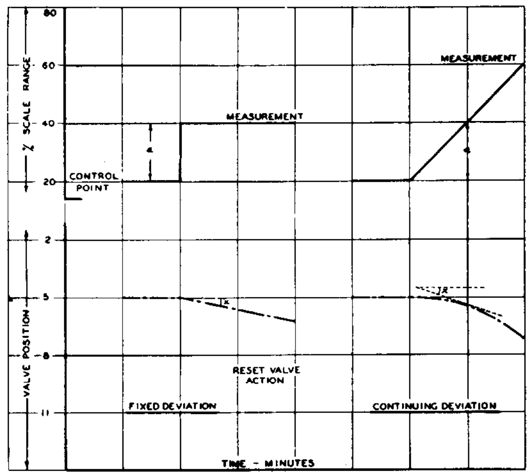

Fig. 3 Fig. 4

Fig. 4 shows the air pressure change on the valve by reset action alone for a continuing deviation of the pen, and shows an increasing reset rate as the deviation increases. However, when the deviation has reached a point equivalent to (a) the rate indicated by angle (X) is exactly the same as the rate shown in Fig. 3 for a fixed deviation.

In Fig. 5, the separate effects of proportional and reset action are shown for a continuing deviation of the pen and at the 50% scale range point in the measurement, proportional action has increased the pressure by the value (b) and reset action has increased the pressure by the value (c). Because these two actions are simultaneous and accumulative, the effect of both actions is shown in Fig. 6.

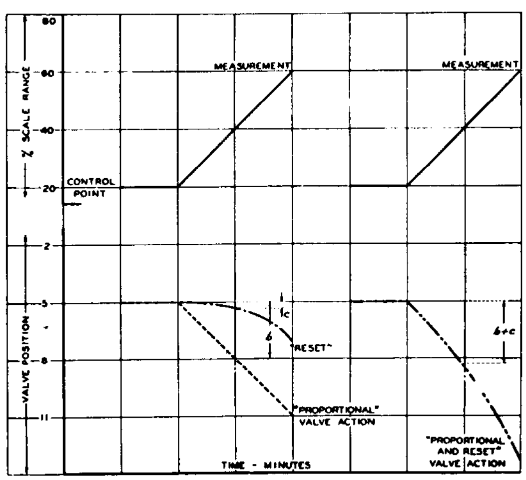

Fig. 5 Fig. 6

Proportional and reset action was used for many years with success, but control requirements became more exacting and it was realized that there was a need for a further stabilizing influence in the control mechanism. The ideal mechanism would have been something that produced an "anticipatory" action, but as anticipation is a function only of the human mind, a truly anticipatory device was impossible. However, a control function was developed which applies a correction proportional to the rate of measurement deviation and which is entirely unaffected by either the amount or duration of the deviation. This function is known as the derivative function. Derivative action is never used alone but always in the combination with either proportional or proportional with reset.

Fig. 7 shows the effect of derivative action on the valve entirely independent of proportional and/or reset. The measurement deviation is exactly the same as in previous figures which is at a constant rate defined by the angle (Y). The valve correction is applied at the instant of measurement deviation from the 20% scale value and the amount of the valve position change is maintained at the value (d), as long as the rate of measurement deviation is constant.

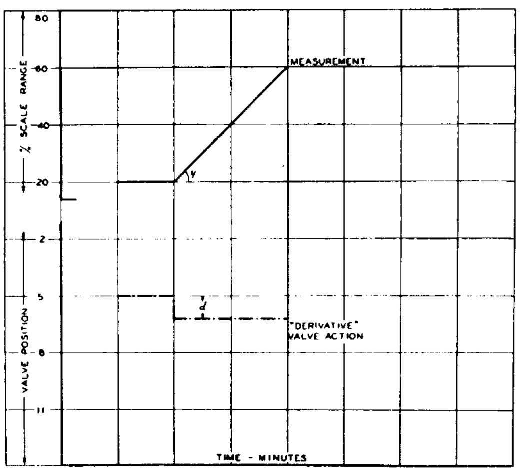

Fig. 7

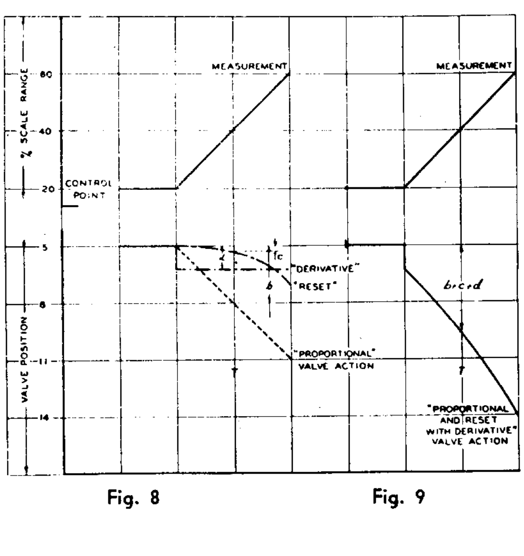

Fig. 8

Fig. 9

The effect of valve position change resulting from derivative action is accumulative with proportional and reset action. Fig. 8 shows the valve position changes resulting from proportional, reset and derivative actions independently, and Fig. 9 shows the accumulative effect of the three functions.

The function of an automatic controller is to maintain process stabilization, and when an upset occurs, the controller should be capable of reducing the amount and duration of instability to a minimum to restore process equilibrium in the quickest possible time. From Fig. 8, it can be observed that with proportional action alone when the pen deviated from 20% to 40% scale range, the valve position was changed by an amount equal to dimension (b). With the addition of reset, the pressure on the valve was increased by a value equal to dimension (c), and with derivative action an additional pressure equal to dimension (d) was applied to the valve. From Fig. 9 it can be seen that when the measurement deviated from 20% to 40% of the scale range, the accumulative effect of all actions produced a change of pressure on the valve equivalent to b + c + d. The effect of the derivative action, therefore, is to apply a change in valve pressure at the instant the measurement starts to deviate, and of an amount proportional to the rate of deviation. This effect is to apply a corrective action sooner than normal proportional action would apply it, with the result that the measurement deviation will be reduced, or to put it another way, the amount and duration of process instability will be reduced.

This latter point is illustrated in Figures 10 and 11. In Figure 10 are shown two recovery curves of an actual process following an upset. The upper curve shows the recovery producted by proportional and reset action only.

The lower curve shows the recovery produced with the addition of derivative action. In Fig. 11, these two curves are superimposed for better comparison. The improvement gained with derivative is at once apparent.

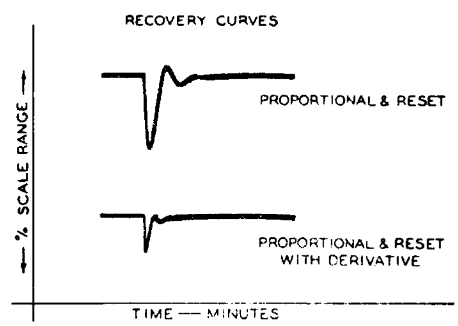

Fig. 10

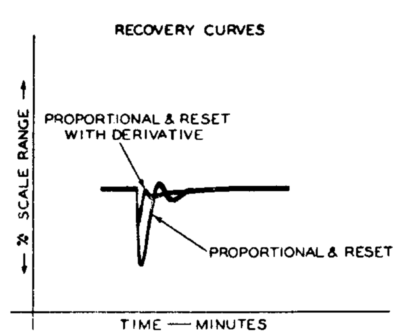

Fig. 11