Electronic Techniques for Automatic Process Control

Part II

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The manner in which an electronic controller changes its output relative to input is known as control action. Modern electronic controllers are usually designed to produce a combination of the following control actions: (i) proportional, (ii) integral, and (iii) deviative.

Each control action has its characteristics, advantages and limitations. To select the best possible control action for a given application, it is important that the characteristics of each action are fully understood.

Proportional action

Proportional action is also known as throttling or modulating action. In this action, there is a continuous linear relation between the value of the controlled variable and the controller output. In other words, the controller output changes by the same amount for each unit of deviation. This action responds only to the amount of deviation and is insensitive to the rate or duration of deviation. There is no change in controller output without deviation.

The change in value of the controlled variable that is necessary to cause full change of controller output, is known as proportional band (PB) or throttling range. The proportional band of a particular instrument is usually expressed as a per cent of its full range. In practical controllers, the proportional band may cover less than 1 per cent to much over 200 per cent. Proportional bands over 100 per cent cannot cause full change in controller output even for full range in the controlled variable.

Another concept for expressing action of proportional controller is gain or sensitivity. These terms describe the ratio of controller output to controller input. Mathematically, gain and sensitivity are reciprocal of proportional band. Fifty per cent proportional band corresponds to a gain of 2. The adjustment of proportional action of a controller is calibrated either in terms of gain or in terms of proportional band.

Any change in process load requires a change in controller output to maintain the controlled variable at the desired setpoint. But a proportional controller requires a change in deviation in order to produce a change in its output. Hence, proportional control action can produce an exact correction for only one load condition.

At all other loads, there must always be some deviation left. This is called offset deviation and is an inescapable characteristic of proportional control action. This offset can be eliminated by manually resetting the setpoint to bring the controlled variable to the desired value. However, it must be emphasised that each change in load requires manual resetting of the setpoint which may not be possible if load changes are very frequent.

Proportional control action works best when process capacitance is relatively large, process reaction rate relatively slow, and process lag and dead time relatively small. All these characteristics promote stability and permit narrow proportional band settings which lead to faster corrective action. When process characteristics are less than ideal, a wider proportional band is used even though this increases offset with load changes.

Excessive gain produces over-correction of the controlled variable beyond the setpoint. It reverses the characteristic of overshooting, once it has reached its maximum and is followed by undershooting which means passing the setpoint because of its inherent inertia. The resulting movement is an oscillation around the setpoint.

The magnitude of response can be reduced by reducing the gain to such a degree that no cycling occurs. This results in a sluggish response which is undesirable in a process where quick correction is required.

The necessary compromise for optimum control is a gain that results in a few rapidly subsiding cycles around the setpoint. The gain necessary for this condition depends on the speed and magnitude of the load change and the time required by the control system to correct the deviation. If the process response is fast, a small gain is chosen and vice versa.

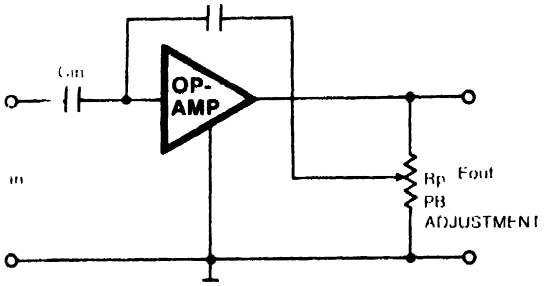

Fig. 4: Controller with proportional (P) action.

High gain results in cycling if process response is too fast. This condition will increase considerably if dead time is present, as it will take longer to correct overshooting. Hence, proportional control should be used in processes with comparatively large time constant and small dead time. The ratio of time constant to dead time should be large, the magnitude of load changes should be small while speed of load changes can be large.

Fig. 4 shows the schematic of an electronic controller with proportional action. The effective ratio of the value of the input capacitance and the feedback capacitance determines the proportional band. The effective value depends not only on the capacitor size, but also on voltage gain of the amplifier. If the effective ratio is 1:1, then the proportional band is 100 per cent.

Proportional band can also be adjusted by regulating the PB control potentiometer. By this adjustment, the amount of output that is used in the feedback circuit can be varied. With a decreasing feedback signal, a larger output must be produced to fully charge C_{fb}. An increased output for a given input is merely a narrowing of the proportional band. A full range of output signals can, therefore, be produced by a small input signal.

Integral action

Also known as proportional speed floating action, the controller output in this action changes at a rate that is proportional to deviation. In other words, the greater the deviation, the faster the controller output changes. As long as the deviation persists, the controller output continuously changes. It responds to both the amount and time duration of the deviation. Thus, this action continues to operate until it does produce an exact correction for any load change. This is the unique advantage of this action over any other action.

Since its rate of correction increases with the size of the load change, it is able to operate well with comparatively fast load changes. For the same reason, the amount of self-regulation can be considerably less.

This action is suitable for processes with small time constant and small dead time. The ratio of time constant to dead time should also be small. It can handle large load changes.

Fig. 5 shows the schematic of controller with integral action. A voltage divider is placed across the input and a variable resistor is placed in parallel with C_{in} for integral action. The voltage divider and variable resistor provide a path for current flow whenever an error signal exists.

This current provides a continuous amplifier input whenever the process variable differs from the setpoint. Feedback current, therefore, continues to charge or discharge the feedback capacitor as long as there is an error input. The amplifier then produces a continuous change in output as long as an input signal exists. This, by definition, is the integral action, since the controller is seeking the null position.

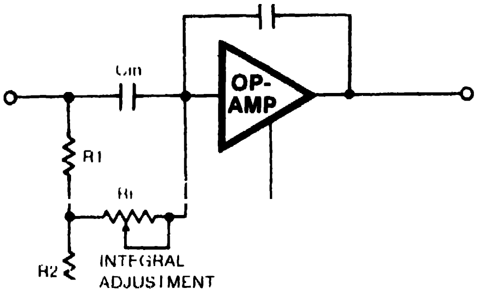

Fig. 5: Controller with integral (I) action.

In this circuit, the only time that the input current stops is when the error voltage is zero. By decreasing the value of integral resistor, input current is increased for a given input signal. The output current must increase at a faster rate in order to produce a matching change across the feedback capacitor. The result is a faster integral rate.

Increasing the size of integral resistor results in a slower integral rate. To produce a very slow integral rate, the voltage divider has been incorporated in the input circuit. The voltage divider causes the integral resistor and amplifier to recognise a smaller portion of the input signal, resulting in a smaller charging current. The input capacitor, however, still recognises the full input voltage. The value of integral resistor determines the number of times that the proportional action is repeated per minute.

Derivative action

This action is also known as differential or rate action. In this action, the controller output is proportional to the rate of change of the controlled variable. The derivative action has a great stabilising effect on control because it opposes any change of the controlled variable. This action has no effect on offset error.

The derivative adjustment is expressed by derivative time in minutes. It is the time by which the derivative action advances the effect of proportional action.

Derivative control is an anticipatory type of control, sometimes called preact, booster action or error-rate damping, in which the correction speed depends on how fast the controlled variable is deviating from the desired setpoint. It measures the rate of change of error and as a result can predict a large overshoot before it occurs so that it can apply corrective action to limit it. As a result, oscillations are reduced.

In this action, either the controlled variable signal or the output signal to the final control element is increased in proportion to the rate of change of signal. The effect is similar to that of a temporarily increased gain. The result is that even a sluggish corrective action becomes sufficiently rapid to furnish satisfactory control.

The acceleration of a changing signal which is inherent in derivative action makes it valuable for long time constants with initially small responses.

The most notable advantage of using derivative action for counteracting the effect of dead time is the reduction of the period of cycling. Thus, the controlled variable is stabilised at the setpoint more quickly when load changes occur.

Derivative time is adjusted to change the response in accordance with the amount of process lag. On process start-up, the initially large correction provided by the derivative action brings the controlled variable to the setpoint very quickly, reduces overshoot, and cuts both the time and the magnitude of cycling.

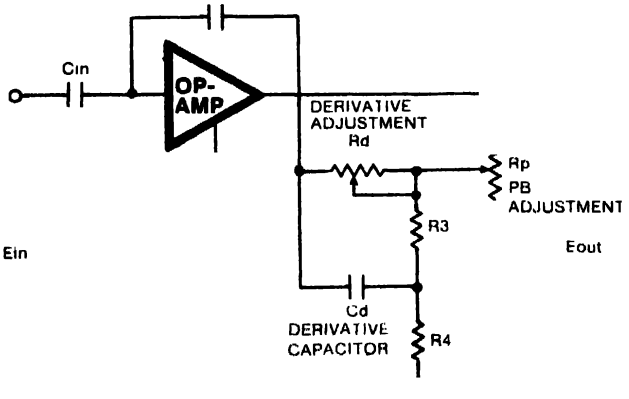

Fig. 6: Controller with derivative (D) action.

Fig. 6 shows the schematic of controller with derivative action. The derivative action is accomplished by the addition of a voltage divider, a variable resistor, and a capacitor in the feedback circuit.

The input error signal change produces an output change that is easily passed by the derivative capacitor. Since this change is taken from across the voltage divider, the result is that the feedback capacitor recognises only a portion of the output. The effect is similar to a decrease in the proportional band control, i.e. the instantaneous effect is a narrowing of the proportional band. This results in a greater output change for a given input until the derivative capacitor charges.

The time taken by the derivative capacitor to charge depends on its time constant. This can be changed by the variable resistor - the derivative time adjustment. As soon as the derivative capacitor charges, the effect of the voltage divider disappears. The proportional band is then restored to its original value. Derivative amplitude will be determined by the voltage divider. This, of course, determines the amount of instantaneous change in the signal fed through the derivative capacitor.

Proportional-cum-integral action

It has been seen that integral action is capable of providing exact correction. Thus, by combining integral action with proportional action, the undesirable offset characteristic of proportional action can be overcome. This combined action is also known as reset action. The major advantage of this action is that control without offset error is possible under all load conditions.

The integral rate adjustment alters the rate of change of the integral component. Integral rate is usually expressed in repeats per minute. This term denotes the number of times per minute that controller output due to proportional action is repeated by the integral action.

The effect of integral action is to add corrective action to the process as long as the deviation exists. This is the same as shifting the setpoint gradually, forcing the controller to follow until the original setpoint has again been reached.

When the deviation occurs, there is an immediate response from the proportional action. This response is increased at a fixed rate by integral action. The output of the controller is proportional to the magnitude and duration of the deviation. This causes prolonged cycling when the load changes occur too rapidly.

This action is suitable for processes with small time constants and small to medium dead times. However, the ratio of time constant to dead time should be large. Large load changes at a slower rate can be handled by this action.

The integral rate adjustment, in combination with the proportional band setting, determines the rate at which the proportional band is shifted when a deviation occurs, and is set in accordance with the process requirements. With a given setting, integral rate is proportional to the amount of deviation of the controlled variable.

When the controlled variable is returned to the setpoint, integral action ceases to shift the PB and leaves it in the position attained at that time. The integral response also depends on the PB setting, being inversely proportional to width of the PB.

The proportional-cum-integral mode of control (PI) is the most useful among all modes. It can handle most combinations of process characteristics satisfactorily. Small capacitances permit a higher integral rate, and enable the controller to counteract offset more quickly. Transfer lag and dead time in the controlled system, however, require a decreased integral rate in order to avoid excessive cycling of the controlled variable.

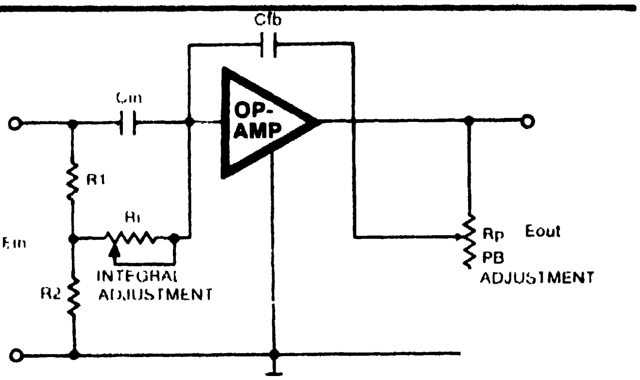

Fig. 7: Controller with proportional-cum-integral (PI) action.

The limitation of the PI control lies in the large period of cycling and the attendant slow response when appreciable dead time is present in the controlled system. Transfer lag is not a serious limitation as long as the measuring device is sensitive. If the measuring device is sluggish, transfer lag is converted to a dead time and PB must be wider with a slower integral rate.

Fig. 7 shows the schematic of controller with PI action. R_p is the proportional band adjustment and R_i is the integral adjustment. The proportional control introduces negative feedback to give stability to the system. The integral control provides a delayed positive feedback to nullify the effect of negative feedback and reduces the proportional band of the system to remove undesirable offset. This positive feedback is introduced with a time lag so that the proportional band will be reduced after it is no longer needed for stability.

Proportional-cum-integral-cum-derivative action

Proportional, integral and derivative actions can be combined in one controller to obtain the advantages of all these actions. A controller combining all these actions is known as PID controller. The output of a PID controller depends on the magnitude, duration and the rate of change of the deviation.

This action might be required where only proportional control would allow the controlled variable to have an excessive offset, when the input changes at a constant rate, and where the incorporation of only integral action would give too small a margin of stability. The addition of derivative control then has the effect of stabilising the system by increasing the damping.

This action overcomes limitations of all other types of control actions. It contains the compensation for large time constants with initial slow response of the derivative action. It also combines the favourable response of proportional action to fast, though small, load changes.

Slow but large load changes can also be handled by the proportional-cum-integral action. Hence, this action can be used for any difficult application where time constant may be small, dead time may be large and load changes may be relatively large and fast.

Processes with a dead time of more than 2 minutes or a large transfer lag are sometimes difficult to control, even with the proportional-cum-integral mode. The proportional band must be set exceptionally wide and the integral rate usually slow in order to avoid excessive cycling. Thus, when load changes occur, there is a rather large deviation, and it takes a long time for the controlled variable to return to the setpoint. In such applications, which are most often found in temperature control, the addition of derivative action to the proportional-cum-integral mode usually solves the control problem.

Basically, the derivative action provides an initially large correction when a deviation occurs, so that the final control element initially moves further than it normally would with proportional-cum-integral action. Then, having made this large initial correction, the controller functions to remove this effect, leaving only the corrective action of the proportional-cum-integral response to determine the position of the final control element. The result is an early, extra change in the process input, which tends to counteract the unfavoura-

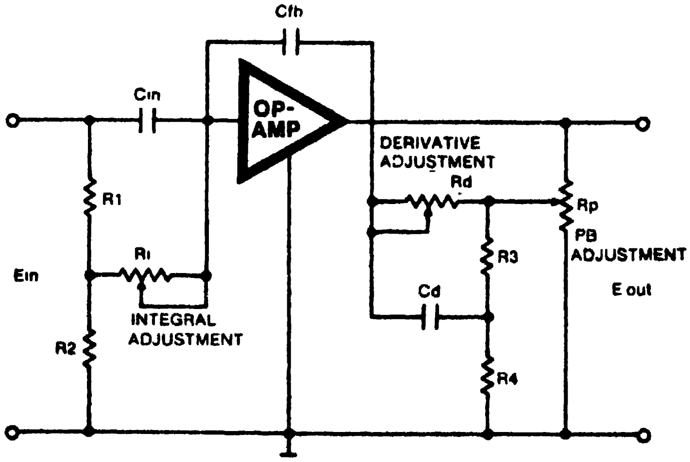

Fig. 8: Controller with proportional-cum-integral-cum-derivative (PID) action.

ble effect of process lag. It is a temporary overcorrection proportional to the amount of deviation.

Fig. 8 shows the schematic of a controller with PID action. Proportional band control adjustment is used to regulate the gain of the system by changing negative feedback to suit the characteristics of the process. Integral adjustment is used to provide positive feedback to eliminate offset when load changes. Derivative adjustment supplies negative feedback which produces a control response proportional to the rate of change of the controlled variable.

System response

A load change in the control system causes the controlled variable to deviate from the setpoint and thus produce an error. The controller then attempts to return the controlled variable to the desired setpoint.

Ideally, a disturbance in the control system should cause the system to respond instantly to produce the exact conditions required. This is impossible in practice owing to various characteristics of the controlled process and control system such as dead time, time constant and damping.

The initial error causes the system to respond in such a way as to reduce the deviation of the controlled variable from the setpoint. The corrective action produced by the final control element, however, usually causes the controlled variable to overshoot the setpoint, thus reversing the error.

The system then starts to correct this error and, as a result, the controlled variable this time undershoots the setpoint with further reversal of error, and so on. In this way, the oscillations of the controlled variable occur in response to a load change.

A system is considered to be unstable if the amplitude of the oscillations is maintained after a disturbance. A stable control system is one in which oscillations introduced into the system die out as time increases. The oscillatory response of the controlled variable to a disturbing signal before the system returns to a quiescent state is known as transient transponse. The response of the controlled variable to a disturbing signal after oscillations have ceased is known as the steady state response.

The type of response that the system makes to load changes is the criterion of the quality of control. The problems concerned with the design of control systems centre around the need to provide stability along with rapid response under normal operating conditions. Systems can often be made stable by introducing various forms of time lag into the system, but if the system is excessively stable its response may be too slow.

Stable systems exhibit several types of response, depending upon their design. The response may be oscillatory with a constant amplitude; it may be oscillatory with a decreasing amplitude; or it may be smooth curve. The most acceptable response is often the form in which the amplitude of each successive overshoot following a disturbance is about one quarter of the previous overshoot.

Selection of control technique

Probably the most difficult decision for automatic control of a process is the selection of an adequate, yet economical, control technique. The solution is usually a compromise between the quality of control desired and the cost of the control system. The control system must be adequate to meet the tolerance of the process, but it should not include refinements beyond those required or its cost will be excessive.

The cost of a control system must be evaluated in terms of what it accomplishes. A mistake often made in the selection of a controller means sacrificing quality to minimise the original cost. This may result in increased maintenance costs, and, as a by-product, loss of production time. These two factors—production loss and maintenance cost—are usually more important than the original cost.

Most control systems are installed with a life expectancy of more than ten years. In many cases this minimises the significance of the original cost.

As plant situations are analysed, it becomes evident that control sophistication and complexity can work against plant efficiency as well as for it. A complex control system that is highly advantageous in one plant where skilled operators and maintenance people are available, might create severe production losses when operated and maintained with less skilled workmen. The experience level of operators and maintenance people must be considered before selecting a suitable control system for a plant.

Each mode of control is applicable to processes with certain combinations of basic characteristics. It is important to remember that the simplest mode of control which will do the job is the best one to use, both for reasons of economy and for best results. Frequently, the application of a very complicated control mode will result in poor control and contribute to the undesirable characteristics of the process.

When narrow proportional bands are used, the integral action is generally not required. Under such conditions, the controller applies large corrections for deviation and offset will not exist even with load changes.

Derivative action is used to reduce long lags. In the measurement and control of rapidly changing variables such as pressure and flow, the addition of derivative action may actually increase the error instead of correcting it. In the measurement of flow with a differential pressure type of instrument, which responds very rapidly, pulsations in flow from reciprocating pumps and compressors will be picked up and transmitted to the controller. The derivative action in the controller will accelerate the corrective action in response to these pulsations and cause rapid opening and closing of the final control element and its ultimate failure.

Considerable experience is required in the selection of the correct mode to suit a particular process. Proportional mode is generally used in processes with fast or medium reaction rate and small or moderate transfer lag or dead time when load changes are small and slow. Pressure and liquid levels are essentially single capacitance processes and come under this category.

Proportional-cum-integral mode is generally used in processes with negligible capacitance as well as small transfer lag and dead time when load changes are slow. Flow control applications come under this category.

Proportional-cum-integral-cum-derivative mode is generally used in processes having two or more capacitances with large transfer lag and dead time when load changes are large and frequent. Temperature control applications come under this category.

Computer techniques

The increasing use of electronic controllers in recent years as hastened the use of computer techniques for automatic process control. Today, large chemical plants being built are using the latest available electronic hardware, computer controls and advanced control concepts such as adaptive and optimal control.

There has been much debate in the past among control system designers about the relative merits of computer versus conventional control systems and direct digital control versus supervisory control. Each system has its own merits. The designer must judiciously select from among these alternatives a system which meets his requirements. No single system is universally superior in all applications.

Computers are now being used to control directly, to perform economic optimisation calculations, to make heat and material balance calculations or simply perform the conventional monitoring, logging and alarm functions. Large computer systems being built today have fully redundant computers with complete, fully automatic transfer of data and controls in the event that on-line computer fails. These systems include sophisticated display features and require complex interface hardware and software techniques.

Minicomputers are being increasingly used in large chemical plants to perform many of the logic and control functions normally associated with conventional controllers. Attractive economic benefits can be realised by controlling and optimising only a few critical loops in a process by using minicomputers. In this way, many of the advantages of computer systems can be obtained with a low capital investment and operating risk. Moreover, these systems can be linked to an overall hierarchial computer management system when the need arises.

There have been significant advances during recent years in the application of advanced control techniques and sophisticated data acquisition, monitoring and control systems in process plants. However, recognition of these advances does not warrant scrapping of existing conventional control systems. Existing controls can be replaced by better and sophisticated controls only when this replacement can be economically justified. □