Electronic Techniques For Automatic Process Control

Part I

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In recent years automatic process control has assumed considerable importance in chemical industry due to complexity of modern processes, increase in plant sizes and production rates, rise in labour costs and decrease in profit margins. There is an ever-growing demand for more and better control techniques as these bring increased productivity and lower production costs, give better and uniform quality of product and greater safety to operating personnel. Electronic techniques have now taken a lead over other techniques for automatic process control because of several reasons.

Reliability. The majority of solidstate control systems available for industrial applications use specially developed semiconductor devices with lives longer than that of the equipment being controlled. Once a new control system using these assemblies has been tested and set in operation, its predictable life is completely independent of duty cycle rate. The absence of any moving parts in solidstate control systems results in completely silent operation and negligible deterioration in the functional characteristics.

Wide experience shows that semiconductor devices are liable to failure only during the initial operating period of test loading and that if a soaking test of sufficient duration is arranged before installation, extremely high reliability is assured.

Speed of response. Where fast operating times are of importance, electronic controls are a natural choice as the absence of moving parts for transferring information through a system means that delays between command and action can be insignificant. With suitable selection of components and careful designing, these delays can be reduced to total periods of a few microseconds.

Cost. With continually improving technology, unit and sub-system costs have been considerably reduced and are likely to reduce further in future. The installed costs of electronic systems are less for large plants where transmission distances are more than 100 metres. The power consumption of modern electronic controllers incorporating solidstate components is also quite low.

Accuracy. Modern electronic controllers have accuracy of ±0.25%. Digital instruments can have even better accuracy.

Maintainability. One of the most significant improvements introduced in the design of electronic controllers is the modular concept of construction. Plug-in assemblies and sub-assemblies have made replacement and repair much easier.

Packaging. There have been many recent improvements in equipment packaging. Large case instruments have been replaced by sub-miniature instruments. Not only have instrument sizes been reduced, but the density of instruments has also increased to provide much more information in a given panel area.

Computer compatibility. Electronic controllers provide convenient, economic interfacing with supervisory digital computers and data processing or data acquisition systems. This has resulted in the use of more advanced control techniques such as adaptive and optimal control.

Control fundamentals

The chemical industries have scores of differing processes. Rigid specifications for each and every product require close control of hundreds of process variables such as pressure, flow, level, temperature etc. These process variables will change unless energy or material input equals output. Thus, the main function of a process control system is to manipulate the energy or material input-to-output relationship of a process, so as to keep the process variables within desired limits.

An automatic controller is a device that measures the value of a process variable and operates to limit the deviation of that variable from the setpoint. A process variable that is held within limits is called a controlled variable. The automatic controller regulates the controlled variable by making corrections to another process variable which is called the manipulated variable.

Control techniques range greatly in complexity. Selection of a control technique to solve a particular control problem requires a detailed knowledge not only of the basic features of the various types of electronic controllers, but also of the physical and chemical characteristics of the process fluids and mechanical aspects of process equipment such as pumps, mixers, reactors, heat exchangers and the interconnecting piping system.

Process characteristics

Selection of a suitable control technique for a particular process depends on its characteristics. Every process exhibits two effects. (i) changes in the controlled variable due to altered conditions in the process, generally called load changes, and (ii) a retardation or delay in the time it takes the process variable to reach a new value when load changes occur, called the process lag. This lag is covered by one or more of the process characteristics of capacitance, resistance, and dead time.

Process load is defined as the total amount of control agent required by a process at any one time. Process load is directly related to the position of the final control element required to maintain the controlled variable at the setpoint. A load change causes deviation of the controlled variable from the desired setpoint value and requires a new position of the final control element. Both the magnitude and the rate of load change are important in selection of the control technique.

The load changes in a process are not always easy to recognise. Some of the causes of process load changes are: (i) greater or less demand for control agent by the controlled medium, (ii) change in composition of the control agent, (iii) changes in ambient conditions, and (iv) changes in process reaction rate.

The capacitance of a process is change in its capacity against some reference. In any process, a large capacitance relative to the flow of control agent may be favourable to automatic control. A large capacitance has a tendency to keep the controlled variable constant in spite of load changes. It will make it easier to hold a variable at a certain value but more difficult to change to a new value.

Although the overall effect of a large capacitance is generally favourable, it does introduce a lag between the time a change is made in the control agent and the time the controlled variable reflects the change. The corrective action brought about by an automatic controller to maintain the balance in the process depends upon the relative rate at which the process reacts.

The second basic process characteristic is resistance, defined as the opposition to flow. If a material is being heated in a process with high thermal resistance, it will take more control agent to effect a temperature change in the material than in a process with low thermal resistance.

Many processes, particularly those involving temperature control, have more than one capacitance. If the flow of energy passes from one capacitance through a resistance to another capacitance, there is a transfer lag.

Transfer lag in temperature control is always unfavourable because it limits the rate at which heat input can be made to effect the controlled temperature. The result is a tendency to overshoot the setpoint, because the effect of the addition of heat is not immediately felt and the controller calls for still more.

The lag which occurs in processes where it is necessary to

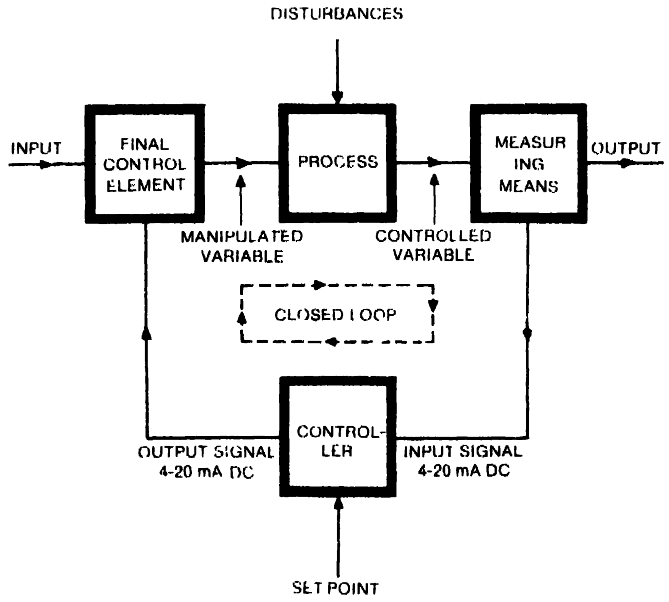

Fig. 1: Closed loop process control system.

transfer energy by means of a fluid flowing through some distance at a certain velocity is called distance/velocity lag or dead time. Dead time is often created by the installation of final control element or measurement system at a distance from the process. Dead time introduces more difficulty in automatic control than does a lag at any other point in the control system. It delays the process reaction and during this interval, the controller cannot initiate corrective action.

Automatic process control system

The function of an automatic process control system is to direct the forces that give stable plant operation by maintaining desired values of process variables. An automatic process control system is essentially a feedback closed loop control system. In closed loop control, the energy input to the system is some function of the output. This effect is commonly termed as feedback. Hence such automatic process control system is known as feedback control system.

The elements comprising a typical control system are represented by the block diagram in Fig. 1. The essential elements of a feedback closed loop system are. process, measuring means, controller and final control element.

The process is the part of the system which performs some desired function. Usually some form of energy entering the process causes the desired operation to take place.

The measuring means essentially consists of a primary sensing element and a transmission system. The primary sensing element detects the process variable to be controlled such as pressure, flow, level, temperature etc. The transmission system produces an electrical output signal, usually in the range of 4 to 20mA DC, proportional to the value of the process variable. The measuring system is usually located in the field near the process and transmits the current signal to the controller located in the control room.

The controller receives the electrical signal from the measuring system. The measuring element of the controller measures the process variable and converts it to a movement on a display device and a control unit. The display device presents the value of the measured variable to the observer.

The control unit consists of an error detector and a control amplifier. The error detector compares the value of the process variable with the desired value and produces an error signal. The error signal is then fed to a control amplifier which produces an output which is a function of the error signal and is suitable in dynamic response and magnitude to actuate the final control element. The controller output also usually lies in the range of 4 to 20mA DC.

The final control element is located in the input to the process in the field. It receives the signal from the controller and by some predetermined relationship changes the energy input to the process to exert a correcting influence on the process.

Operation of the control system

Assume that the system is operating at equilibrium conditions, that is, the controlled variable equals the setpoint value and there is no error. Now, if a load change occurs in any part of the system, the equilibrium conditions are disturbed and controlled variable changes. This change produces an error, which is detected by the error-detection mechanism of the controller.

The error signal to the control amplifier causes the controller to produce an output signal which is the result of the error. The final control element, upon receiving the signal from the controller, changes the energy flow to the process.

The altered energy flow brings the controlled variable signal back to the desired setpoint, if the system is correctly designed and operating properly. This sequence of operations repeats itself as long as there is an error.

The controller operates only when there is an error. It cannot predict future action of the control system. The purpose of the control system is to reduce the error when it occurs to zero as quickly as possible with a minimum amount of cycling.

Electronic controller

Electronic controller essentially consists of an error detector, control amplifier and RC networks. It receives a DC input current signal from the transmitter and provides a DC output current signal to the final control element. Input and output signal level is generally 4 to 20mA DC. The output current of the controller can drive a final control element up to 1.5k impedance.

The error signal is generated in an error detector (Fig. 2). The error detector essentially consists of a precision resistor of 62.5 ohms and a precision potentiometer. A zener-stabilised reference voltage of 1.25V DC is connected across the potentiometer. The input signal current of 4 to 20mA DC is passed through input precision resistor which produces a voltage signal of 0.25V to 1.25V DC.

The error detector senses the magnitude and direction of the difference between the controlled variable and the setpoint. The setpoint is adjusted by moving the pointer to the desired value along the indicating scale of the controller by a knob. This also moves the setpoint potentiometer so that a precise voltage equivalent to setpoint value is impressed across the potentiometer.

The input signal is compared with the setpoint signal and any difference is sent as an error voltage of -1V to +1V to the

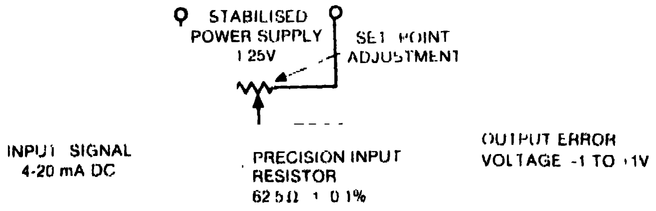

Fig. 2: Error detector circuit of the controller.

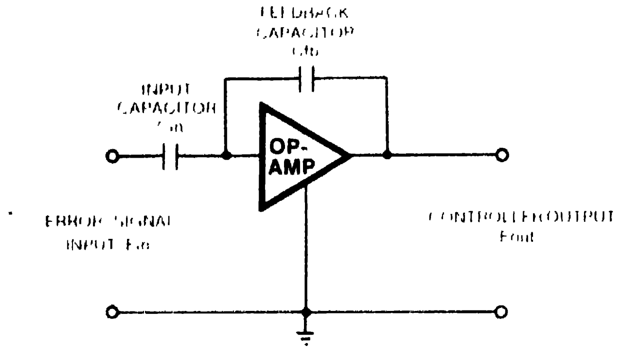

Fig. 3: Basic operational amplifier circuit of the controller.

control amplifier. The error signal is negative or positive depending on whether the controlled variable signal is above or below the setpoint signal. When the process variable and setpoint signals are equal, the process pointer and setpoint pointer 'line up' and there is no error signal

The control amplifier amplifies the error signal to the level required for operation of the final control element. The control amplifier is essentially an operational amplifier which is provided with external variable RC network for producing various types of control responses.

The operational amplifier is a chopper stabilised DC amplifier of very high gain. Various control actions are produced by changing feedback of the control amplifier through RC networks of variable time constants. There is a considerable difference between the open loop and closed loop gain of the system. Inclusion of negative feedback considerably reduces the gain of the system and linearises the system. This increases the stability while decreasing the sensitivity of the system.

The operational amplifier circuit shown in Fig. 3 is the basis for controller action. It consists of an input network and a feedback network in which the current is equalised by the amplifier. If the input current is constant, C_{in} charges to that voltage. The feedback current, produced by this input voltage, charges the feedback capacitor C_{fb}. Once the two capacitors are equally charged, no current will flow. The slight excess of input current necessary to sustain amplifier output is insignificant.

An input error signal causes an input current to flow, charging C_{in}. This amplifier input immediately produces an output or feedback current. Feedback current charges C_{fb} to a value that equals the charge on C_{in}.

Since the reaction of the amplifier is practically instantaneous, the feedback current constantly tracks the input error signal. As these two equal currents vary, adding to and subtracting from the charge of the capacitors, these charges always remain the same. As a result of this action, the summing junction of these two capacitors is always essentially at a ground potential.

(To be concluded)