Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 5—Controllers and Control Systems

API RECOMMENDED PRACTICE 550
FOURTH EDITION, JULY 1985

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Washington, D.C. 20005

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SECTION 5—CONTROLLERS AND CONTROL SYSTEMS

5.1 Scope

This section presents recommendations for the application and installation of automatic controllers and control systems. A brief discussion of programmable controllers is also included. Definitions of control terms are provided, and controller types are described. A presentation of distributed control systems, other than user programmable, is included. Computer-based control systems that are user programmable are covered in RP 550, Part I, Section 14.

Modes of control most frequently applied in the refining industry are discussed along with an empirical approach to controller tuning. Special control applications, such as cascade and feedforward, are also discussed, including digital blending systems.

Some of the environmental and safety considerations for the location and mounting of controllers are discussed. Guidelines are provided to aid in the design and installation of both pneumatic and electronic control systems. Finally, some considerations for acceptance testing and check out are reviewed.

5.2 Referenced Publications

The latest edition or revision of the following publications are referenced in this text

ANSI[1]
MC85.1M *Terminology for Automatic Control*

ISA[2]
S51.1 *Process Instrumentation Terminology*

5.3 Terms and Definitions

The following terms are used frequently in this text. The definitions presented are based on ANSI MC85.1M.

An *automatic controller* is a device that operates automatically to regulate a process variable. This is accomplished by comparing a measured process variable with the desired value of the variable, called the set point, and generating an output signal to a control element.

[1]American National Standards Institute, 1430 Broadway, New York, New York 10017.
[2]Instrument Society of America, PO Box 12277, Research Triangle Park, North Carolina 27709.

Control action, proportional, provides a continuous linear relationship between the output and the input.

Control action, integral (reset), provides an output that is proportional to the time integral of the input (that is, the rate of change of the output is proportional to the input).

Control action, derivative (rate), is that component of the control action for which the output is proportional to the rate of change of the input.

Control action, proportional plus integral (reset), provides an output that is proportional to a linear combination of the input and the time integral of the input.

Control action, proportional plus derivative (rate), provides an output that is proportional to a linear combination of the input and the time rate-of-change of the input.

Control action, proportional plus integral (reset) plus derivative (rate), provides an output that is proportional to the linear combination of the input, the time integral of the input, and the time rate-of-change of the input.

Control, direct digital, is control performed by a digital device that establishes the signal to the final controlling element.

Controller, direct acting, is a controller in which the value of the output signal increases as the value of the input (measured variable) increases.

Controller, reverse acting, is a controller in which the value of the output signal decreases as the value of the input (measured variable) increases.

A *control system* consists of the hardware and software devices necessary to satisfy functional requirements of an operating facility.

Dead band is the range through which an input can be varied without initiating a response.

A *direct connected controller* receives its inputs directly from the process by electrical, mechanical, or hydraulic means.

Distributed control systems are configurable multiloop control systems in which the user defines the control arrangement within a rigorous format provided by the manufacturer. Distributed control systems are generally not considered user programmable.

Gain, proportional, is the ratio of the change in output due to proportional control action to the change in input.

Gain, derivative action, is the ratio of the maximum gain resulting from proportional plus derivative control action to the gain due to the proportional control action alone (sometimes referred to as rate gain).

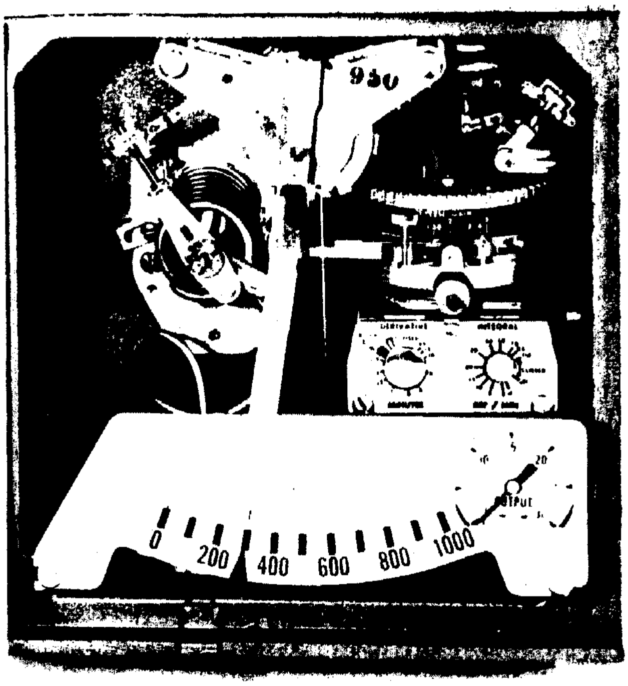


Figure 5-3—Direct-Connected Controller

electronic instruments, which, in the early stages of development, simply duplicated the functions of pneumatic equipment and followed the same packaging concepts very closely. The packaging similarities were intended to provide the process operator with the least possible change in the presentation of information and in the means of changing set points or switching an instrument from automatic to manual.

In the past few years several new approaches have been taken by manufacturers in the architecture or packaging of instrument systems as well as in the design of the operator interface. These variations, generally referred to as distributed control systems, have been made possible by the advances in electronic technology and the lowering costs of digital equipment. Some incentives to use these systems include:

1. Reduced installation costs.
2. Reduced space requirements for control areas.
3. The ability to test the complete system in the vendor's shop.
4. Improved computer interfaces.
5. Improved operator interface.
6. Built-in diagnostics.
7. Improved system reliability.
8. More efficient report generation.
9. Increased flexibility.
10. Improved unit control.

Distributed control systems are defined as those in which the various functions of controlling, indicating, recording, interfacing, and communicating are distributed among a hierarchy of devices that operate both individually and collectively. They have a number of inputs and outputs varying anywhere from a few to several hundred. Instead of the control function being achieved through multiple, standalone, self-contained single loop controllers, a distributed control system may take a number of different forms. These systems are intended to simplify installation, improve means of interrelating and extending controller functions, permit the use of common (or shared) devices, or facilitate interfacing a separate computer system. The extent to which these features can be achieved will vary among manufacturers. Because there are so many systems available, it is not possible within the scope of this document to consider all variations. Several forms of distributed control systems that have been applied to refinery processes will be reviewed to emphasize the differences and the available options.

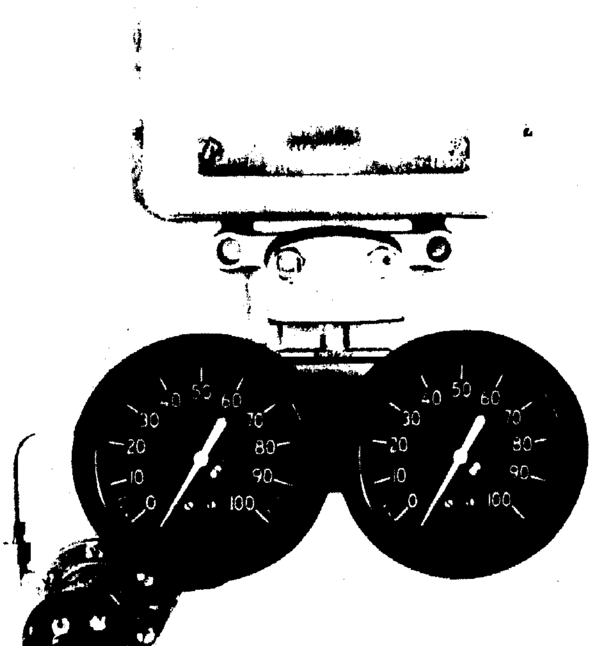


Figure 5-4—Blind Controller with External Gages

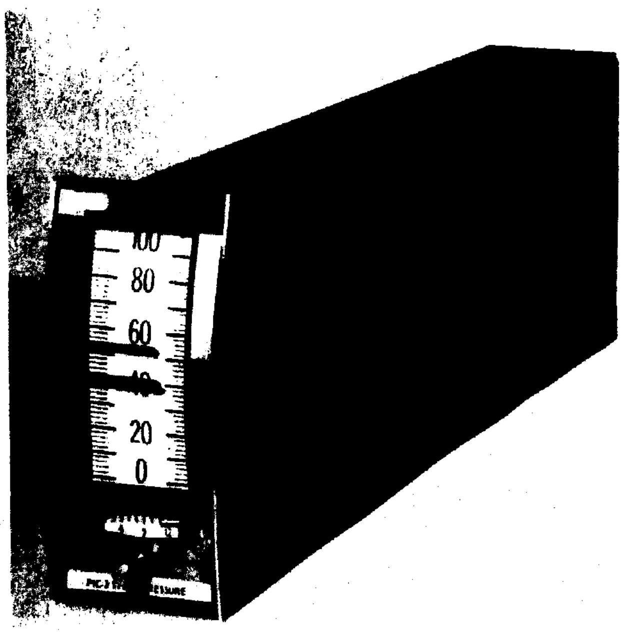


Figure 5-1—Small Case Indicating Controller

A *programmable controller* is a device whose primary function is sequential logic control. A programmable controller accepts binary inputs, generates binary outputs, and in many cases, accepts and generates analog signals.

Receiver controller is a controller that receives its input from a remotely mounted transmitting device such as a process transmitter or transducer.

Set point is an input variable that sets the desired value of the controlled variable. (The input variable may be manually set, automatically set, or programmed. It is expressed in the same units as the controlled variable.)

For additional information see S51.1, *Process Instrumentation Terminology*,

5.4 Single Loop Controllers

Single loop controllers are available in many sizes and shapes but are generallly referred to as small case controllers, nominally 6 inches by 6 inches (150 millimeters by 150 millimeters) or smaller, and large case controllers, nominally 8 inches by 10 inches (200 millimeters by 250 millimeters) or larger. While small case controllers are usually mounted in the control room, large case instruments are more commonly used for field installations. There is a large variety of cases available for large-case controllers, including weatherproof, watertight, and explosionproof cases.

There are three basic types of single loop controllers:

1. Blind controllers, having no indication of measured variable, set point, or output.
2. Indicating controllers, generally having a display of the measured variable, set point, and output.
3. Recording controllers, recording the measured variable on a circular or strip chart and usually including a display of the measured variable, set point, and output.

When recording is required with small case controllers, it is usually done with a separate instrument.

Controllers may be either connected directly to the process or receive an input from an external source such as a transmitter. Direct-connected controllers are mechanically, electrically, or hydraulically connected to the measured variable via a pressure element, thermocouple, filled thermal system, or other means. The signal for the receiver-type controller is usually 3 to 15 pounds per square inch gage (20 to 100 kilopascals gage) pneumatic or 4 to 20 milliamperes direct current electronic.

Controller features that must be specified include: required control modes, ability to switch from manual to automatic operation, local or remote set point, and optional functions. Figures 5-1 through 5-4 illustrate typical single loop controllers.

5.5 Distributed Control Systems

The evolution of process control instrumentation has been more rapid in the last few years than ever before. Pneumatic instruments, although still widely used, have given way to

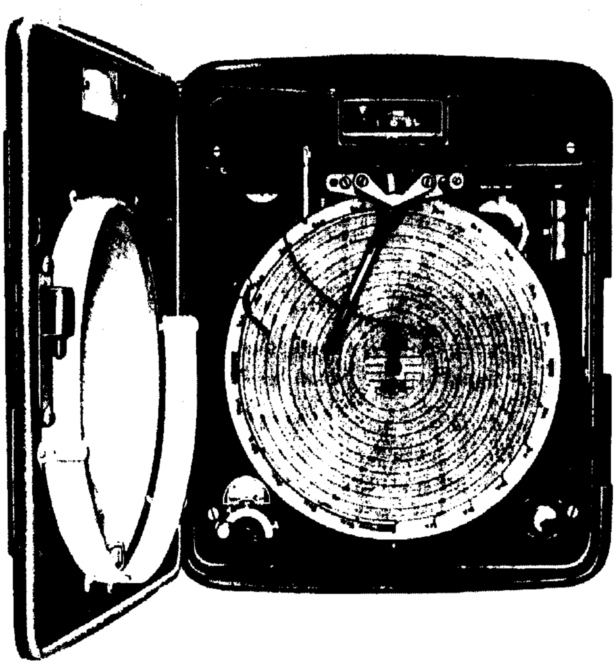


Figure 5-2—Large Case Recording Controller

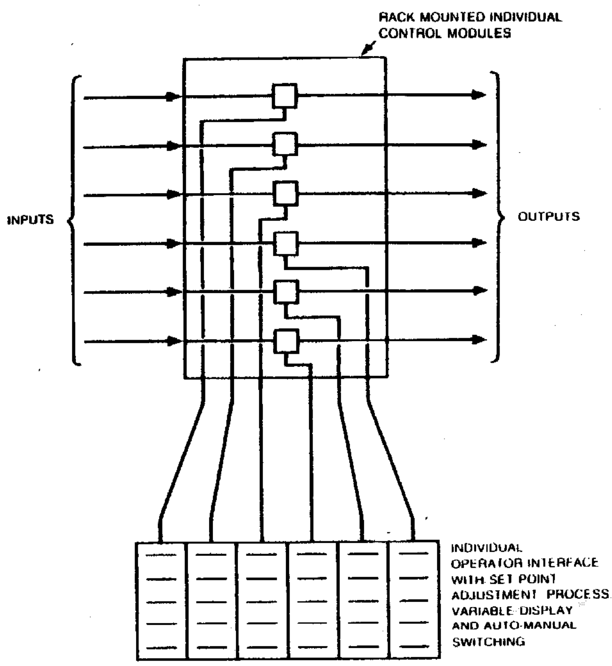


Figure 5-5—Rack Mounted Individual Control Modules with Individual Remote Operator Interfaces

5.5.1 TYPES OF DISTRIBUTED CONTROL SYSTEMS

5.5.1.1 Individual Control Modules

As indicated in Figure 5-5, this configuration consists of rack-mounted individual control modules and individual remote operator interfaces. The physical features of such a system are primarily the rack mounting of equipment, the provision of common power supplies, prewired termination facilities, and prewired positions into which additional printed circuit cards can be plugged. Interwiring between modules can be done at the factory. With the use of plug-in connnectors to the individual operator interfaces, the installation wiring is essentially reduced to inputs from and outputs to the field devices. Factory wiring permits the use of automated equipment, reducing wiring errors.

Individual control modules lend themselves to the addition of features that permit interfaces to a communications network and the use of shared devices, such as a central computer and the operator interface shown in Figure 5-6.

Individual control modules provide continuous control of each individual loop.

5.5.1.2 Microprocessor-Based Multiloop Control Modules

Some manufacturers provide a microprocessor-based system (as shown in Figures 5-7 and 5-8) that accommodates a number of control loops with individually selectable control algorithms. Such systems allow control relationships between variables to be programmed. Many advanced control strategies can be devised without requiring additional equipment or wiring changes. With some systems, a separate programming or configuration device is required.

The operator interface can consist of individual modules, as indicated in Figure 5-7, or an interface can be provided, as shown in Figure 5-8. Through an interface, a communication network can transmit information to a computer or a shared operator display.

The microprocessor-based multiloop system is a shared controller that scans inputs and updates its outputs in cycles. In effect, the control loop whose "turn" it is to function, consults its memory for current process value, set point, control program, and the last output value and "connects" itself to the common controller. There it selects the required algorithm or algorithms and computes a new output value. The process is then repeated for the next loop.

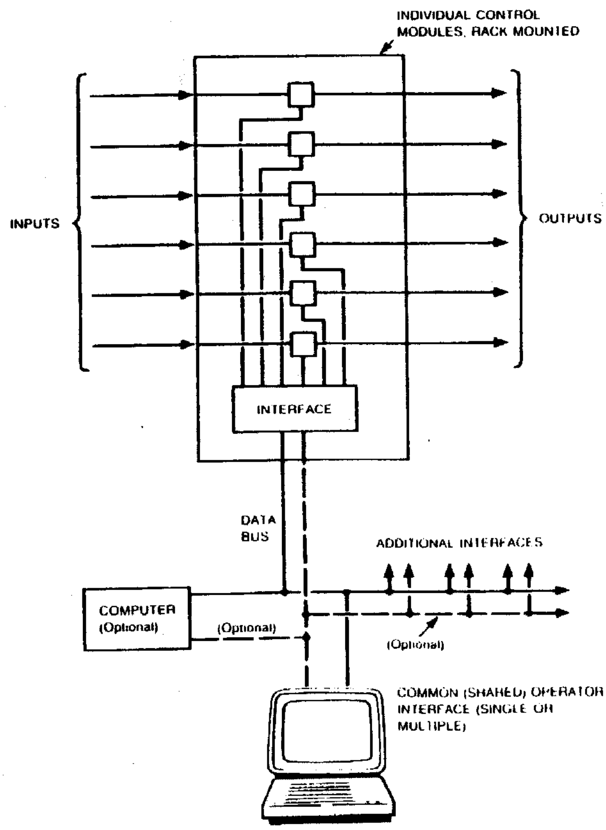


Figure 5-6—Rack Mounted Individual Control Modules with Common Remote Operator Interface and Optional Computer Interface

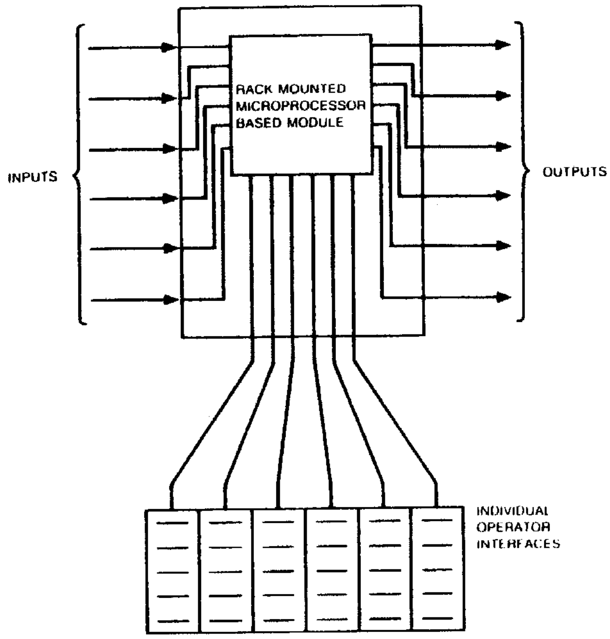


Figure 5-7—Microprocessor-Based System for Multiloop Control with Individual Remote Operator Interfaces

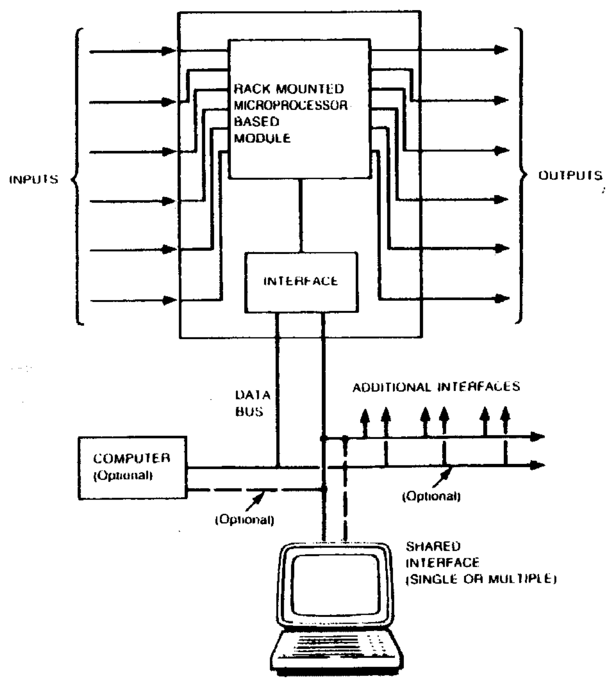


Figure 5-8—Microprocessor-Based System for Multiloop Control with Shared Remote Operator Interface and Optional Computer Interface

5.5.1.3 Computer-Based Process Controller

Some process control systems utilize a single computer (see Figure 5-9) dedicated to a number of loops sufficient for one or more process units. While this computer may have some features that are software selectable, it is generally a self-contained package with both the software and hardware determined by the manufacturer and dedicated to process control.

These process controllers may use microprocessor technology. They have memories, use digital communications, and usually have cathode ray tube displays and a keyboard for communications. As with microprocessor-based control modules, these computer-based controllers can provide some very intricate control systems, including logic and calculation capability, without the need for additional equipment or wiring modifications. They are usually limited to control systems having up to a few hundred loops because they are not modular but monolithic in design.

5.5.2 FLEXIBILITY OF DISTRIBUTED CONTROL SYSTEMS

Most of the features of distributed control systems have been and are available through the use of individual components mounted and wired on a conventional upright panel or console. Such arrangements, however, have limited flexibility and expandability because equipment must be added or wiring changed to add or modify control strategies. The benefits of a computer control system that could add loops,

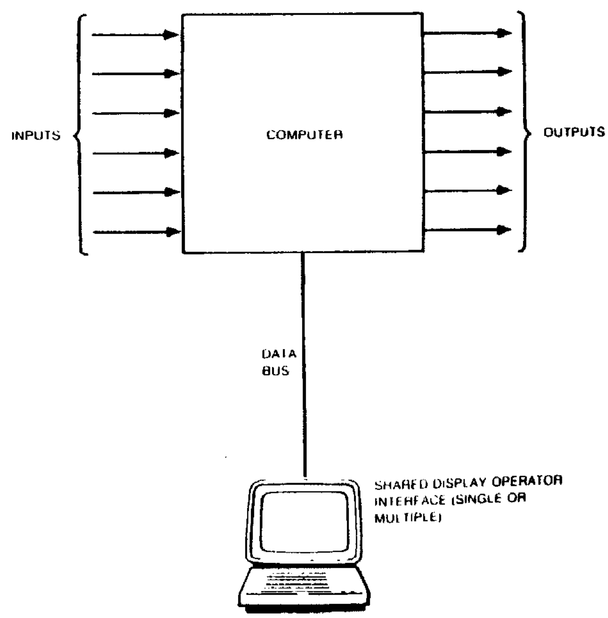


Figure 5-9—Computer-Based Process Controller for Multiloop Control with Shared Display Operator Interface

implement complex control strategies, provide alarms, and change ranges simply by changing software, led instrument manufacturers to look for a means of incorporating these features into their instrument systems. The distributed control systems now available accomplish these features in varying degrees.

The user can now obtain instrument systems that incorporate alarms, keyboard-assignable trend recording, linearization of signals, sequencing, and interlocks, as well as many control algorithms, including error squared, timing, ramping, high-low selecting, and many others. In some cases, the control strategies can be selected by simple keyboard entries.

An additional new feature is the capability of adding loops because of the modular nature of the systems. Care must be exercised initially to ensure that there is spare capacity provided in the modules. The cost of having to add a new rack, power supply, and cabling and wiring for a single loop can be a deterrent if modules are already full. Generally, distributed systems make it easier for the instrument engineer to provide a total control room package. The prospective user should consider how completely each system meets his needs and how easily it will accommodate his special requirements.

5.5.3 GEOGRAPHIC DISTRIBUTION

As indicated in Figures 5-5 through 5-9, the various elements of distributed control systems may be in different locations. While this is usually limited to the separation between the operator interface and the rest of the systems, it can also apply to individual racks of equipment and central computers once an interface has been provided to a data bus (Figures 5-6 and 5-8). Communication is then performed by high-speed digital techniques that provide rapid update of commands and display of multiplexed information. The data bus, which can also be referred to as a data highway or communication network, usually consists of coaxial cable or one or two multiconductor cables, minimizing the wiring between locations.

Distributed control systems employing a data bus can usually accommodate a number of shared operator displays as indicated in Figures 5-6, 5-8, and 5-9. Display stations can be located in various geographic areas throughout the plant (provided a suitable environment is obtained) or, alternatively, the control systems may be installed in the plant area to minimize wiring lengths, while the operator interface is located at some remote central point.

Geographic distribution can be an important feature of the distributed control system. The user can selectively centralize or disperse the control system functions to best meet the operational, maintenance, management, and safety needs of the plant. Past trends in instrumentation have moved from decentralized control (self-contained controllers mounted directly on the process units) to centralized control rooms. The driving force for centralization was the improvement in process operation resulting from centralized information and decision-making. It was also less expensive to protect centralized equipment from severe environments and accidental damage. However, as plant complexes grew in physical size, the cost of wiring to and from a centralized control room also grew and lower cost alternatives were sought. A further consideration is the desire to minimize loss of control as a result of a process accident close to or within a centralized room.

Now the user may choose to locate the data gathering and control functions near the processing units to minimize wiring costs. A data bus then brings the process information to a local or central control room where supervisory control decisions are made and exercised directly from an operator's console. The same data can be supplied to a computer via the data bus to permit higher levels of control. The cost of providing an environment and electrical area classification in the field suitable for the electronic equipment must be considered.

5.5.4 ALGORITHMS FOR CONTROL AND COMPUTATION

Distributed control systems provide at least the normal combinations of control algorithms. Most offer more complex algorithms, such as error squared, high/low select, lead/lag functions, ramping, and time delay, which are selectable to meet the requirements of more exacting control applications. The user should be sure that his needs are met by the system being considered. The availability of various controller configurations, such as cascade, ratio, and feedforward, should also be considered. There should be provision for transfer from one operational configuration to another, including the tracking and display of information necessary to make transfers with minimum disturbance to the process.

Most distributed control systems have computation capabilities that can be incorporated into control configurations. Included among these are square root extraction of signals from head-type flowmeters and linearization of temperature signals from the various types of thermocouples. With such features, the displays can be more easily read and interpreted, and internal calculations can be simplified. The more fundamental computations of adding, multiplying, dividing, and averaging are also provided in most systems and can be used to calculate mass flow rates and heat loads and for temperature and pressure compensation.

5.5.5 OPERATOR INTERFACE

Single loop controllers usually incorporate an operator interface consisting of individual displays of the process variable, the set point, and the output (see Figures 5-1 through 5-4). In addition, there may be means of adjusting the set point, changing ratios, switching to manual operation, and adjusting the output manually. The same features are provided for distributed control systems that use individual modules as operator interfaces (see Figures 5-5 and 5-7). Many distributed control systems now use a common or shared interface instead of individual displays. There may be one or more devices on which the operator can select the information and make the operational changes required. Instead of using the knobs and switches associated with individual modules, an integral keyboard provides the operator with a central point from which he can run the process unit.

The most common approach to the shared display is the use of one or more cathode ray tubes to present the process information to the operator. Information usually includes the current value of the process variable; set point and output; the control mode (automatic, manual or computer controlled); whether the set point is local or remote; controller settings (proportional, integral, and derivative); alarm limits; loop tag number and description; and a history of the process variable, such as would be seen on a recorder. This information is generally supplied in one or more fixed formats, but the particular grouping of variables is user selectable to correspond with the logic of the process. Typical displays are shown in Figures 5-10 and 5-11. In most instances, an analog display format (Figure 5-12) is used because it is similar to single loop controllers, which operators have little difficulty identifying. Hard copy printers are available to provide permanent documentation of any display.

Process alarms may also be brought to the operator's attention on the cathode ray tube by flashing or highlighting the alarmed variable. This may be accompanied by an audible signal. Since the alarm function is shared, its reliability and redundancy must be evaluated, and additional dedicated alarms may be required on certain variables. The system may be equipped with an alarm logger, which prints each time an alarm occurs. Loggers generally print the tag number, some type of loop identifier, the type of alarm, and the time of occurrence. They may also log the operator's alarm acknowledgment and the time the alarm clears or returns to normal. The logger may also print operator-initiated changes to the control system, such as set point, controller mode, and alarm settings. Since alarms are sometimes incorporated into safety shutdown systems and other types of logic networks, the system may provide switch contacts for external use.

The cathode ray tube should provide a means of displaying trends and historical data as a part of the operator interface. This may also be accomplished using strip chart recorders, which can be assigned from the keyboard. Not only should a means of easily selecting the variables be available, but also the facility to change the time base should be provided, since recording needs may change from start-up to normal plant operation.

5.5.6 BUS STRUCTURE AND PROTOCOL

Bus structure and protocol define how the system sends information from one unit to another on the data bus, the priority that each unit and message type may have, and the security and integrity of the message.

There are a variety of bus structures and bus protocols. Each has advantages and disadvantages, but the type used is unique to a given system. The user should determine if his performance criteria are met, rather than analyze the technicalities of the various systems. Significant factors for the user to consider are the maximum length of the bus, the type of wire used for the bus, and the system architecture. The system architecture (both hardware and software) determines what the data transfer rates must be to accomplish a system function or make a functional transaction. Data transfer rate is a function of hardware speed and transaction efficiency of the highway and can affect the response time of operator interfaces and limit the number of loops that any given system may contain.

5.5.7 DIAGNOSTICS

When viewed as a whole, the distributed control system can be a very large collection of complex electronic circuitry. Maintenance and servicing of such a system could be a very difficult task requiring a skill level higher than many maintenance organizations may have and more time than plant operations can afford.

To help minimize the servicing problem, the distributed control system is equipped with on-line diagnostics. These are electronic circuits that monitor the operation of the system and detect faults, bringing them to the attention of the operations and maintenance personnel. They may also disconnect the faulty circuits from the system to prevent the propagation of the fault and minimize its effect on the process under control. For maintenance purposes, off-line diagnostics are generally available. Since the diagnostics identify the location or zone in which the fault has occurred, the maintenance personnel are able to replace the circuit board or boards that have failed in a minimum time and with minimum interruption of operations.

5.5.8 RELIABILITY

With individual single loop controllers, the reliability of the type of device selected should be sufficiently high that operations or maintenance are not significantly affected. A few failures per year can be tolerated and, apart from critical loops, cause no major problems. Such is not the case with distributed control systems where the failure of shared devices can affect multiple loops. The question of reliability

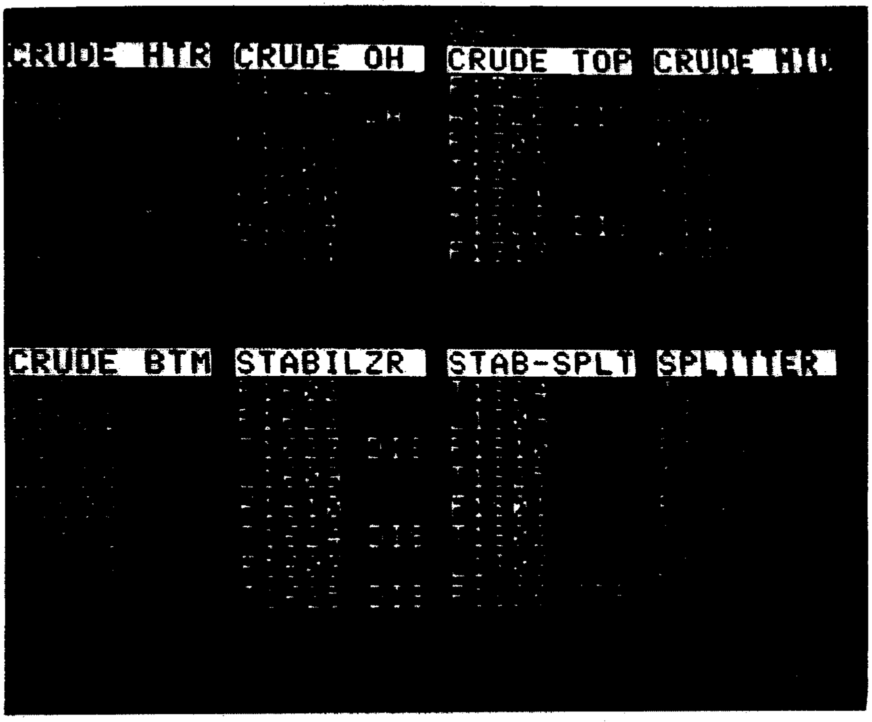


Figure 5-10—Alarm Displays for Operator Cathode Ray Tube

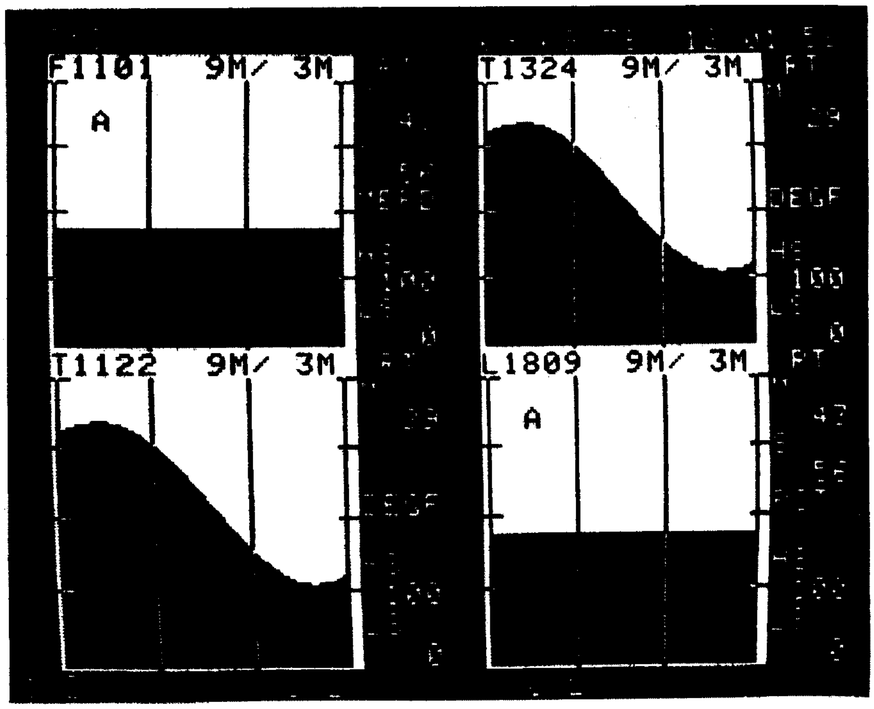


Figure 5-11—Trend Displays for Operator Cathode Ray Tube

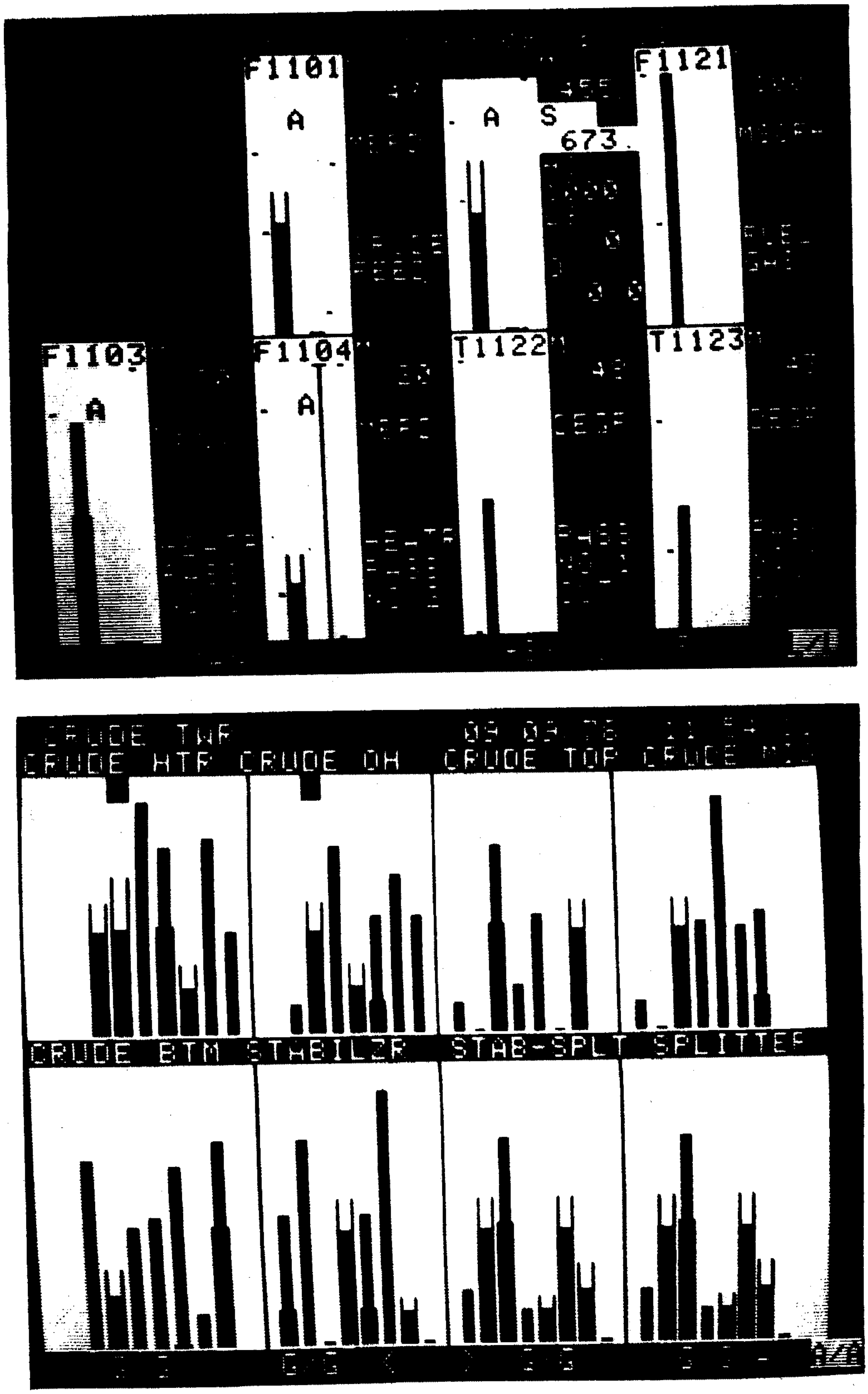


Figure 5-12—Analog Displays for Operator Cathode Ray Tube

of operation now becomes one that has to be assessed very thoroughly.

Analysis of failure modes is required to determine what will happen when various types of failures occur. Such an analysis starts with the controlled devices and determines what action they will take on loss of motive power or loss of signal. The analysis must extend through and include the control mechanism, the interfaces, the data bus, displays, alarms, and power supplies. If the failure cannot be tolerated, which is often the case with shared devices, then it will be necessary to provide a redundant or backup component or system.

In most instances manufacturers have recognized the need for a high level of reliability in the petroleum industry and offer backup systems wherever they are required. Operator cathode ray tube displays are usually at least duplicated. Data highways and their associated interface units can be duplicated, and the highway control systems, almost without exception, have redundancy available as a standard feature.

The control unit may not have a backup as a standard feature, but the circuitry is usually designed to ensure that component failures result in frozen outputs to the controlled devices. Various degrees of backup are nevertheless available ranging from plug-in, manual, analog control stations to automatically switched, redundant microprocessors. The user can select a scheme that is consistent with the requirements of the process.

5.5.9 POWER SUPPLY REQUIREMENTS

Usually the manufacturer takes into account the effect of failure or momentary interruption of the normal power supplies to distributed control systems and provides a backup power supply with the necessary sensing and switching arrangements required for sustained operation.

The effect of power outages or dips should be evaluated based on two types of response: effects on system outputs (signals to valves) and effects on the data base. A power interruption will probably cause the output of electronic controllers to fall toward zero. The use of digital circuitry to store the data base (set points; controller proportional, integral, and derivative settings; and display units) may result in loss or distortion of this information during short power outages. Such loss may result in a control system failure. Depending on the characteristics of a particular system, it may be necessary to use battery backup or an uninterruptible power supply.

The method of reloading the system data base and recovery characteristics of the system outputs should be carefully considered by the user.

5.5.10 SITE PLANNING

Particular attention should be paid to power wiring, grounding, space, and environmental requirements in accordance with the manufacturer's site planning manual and related documents.

5.6 Programmable Controllers

A programmable controller is primarily used to replace a group of electrical relays to do sequential logic control. It is defined as a device that accepts binary (on-off) inputs, generates binary outputs, and in many cases, accepts and generates analog signals. The binary inputs come from devices such as push buttons, limit switches, and other contact devices. The binary outputs are used to send signals to devices such as motor starters, stepping switches, and solenoid valves. The programmable controller may also accept and transmit analog signals used for control purposes. The programmable controller is a microprocessor-based control system designed to perform sequence and logic control. It replaces electromechanical equipment such as relays, stepping switches, timers, drum programmers and, in some cases, analog controllers. Programmable controllers, in general, have been designed and packaged for operation in industrial process environments, requiring high reliability and extended operating life.

The logic sequence program, usually implemented by push buttons or other initiating devices (such as a computer), simplifies the development and checkout, as well as the maintenance of the control system design. This is easily accomplished because of the ease of simulating the actions to be performed by the programmable controller. The user has the option of selecting a pre-programmed controller or doing his own programming through a programming device. Self-checking and diagnostic routines are available as an option.

The programmable controller consists of four functional sections: (1) a memory, (2) a logic processor, (3) storage registers, and (4) input/output signal conditioners. The size of the memory determines the logic storage capacity.

The processor continuously scans field inputs, solves the user's logic program and updates field outputs. To communicate these input/output signals, storage registers accept the field signals and feed them to the high speed circuit of the logic processor. Input/output signal conditioners have special circuits that protect the processor from external electrical noise, which might cause false operation. Noise isolation provides security for the logic program. The logic program is protected during power interruption by special circuits that prevent the loss of memory; thus allowing the progammable controller to be operational immediately after power restoration.

The programming language commonly used to describe sequential on-off logic is an electrical ladder diagram with logic line numbers and programming symbols. The logic con-

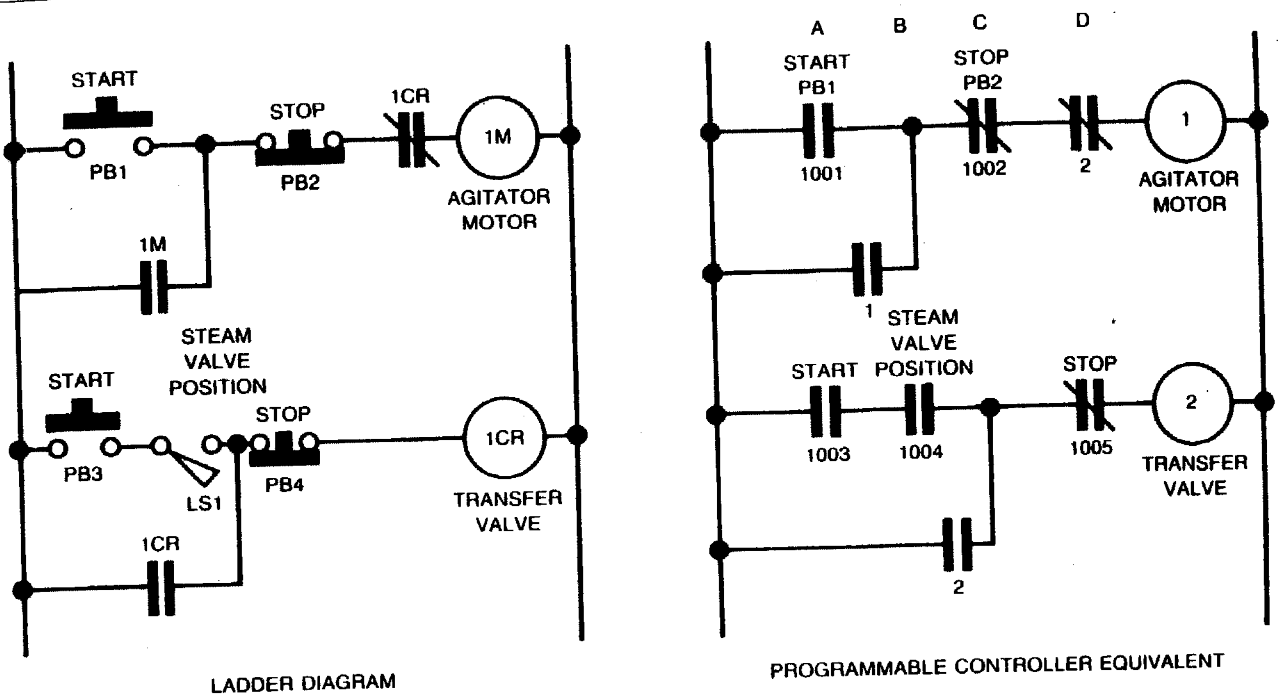


Figure 5-13—Program Language Format

trol program will closely resemble the format used for electromechanical relay systems (see Figure 5-13). Flow charts and ladder diagrams are critical to successful implementation and use of programmable controllers. Unlike electromechanical relay logic systems, programmable controller logic resides in a memory, which can be easily modified to allow for changes in the applications or to correct errors in initial programming.

5.7 Control Actions

Users generally apply various control actions (modes of control) based on their experience and on manufacturers' recommendations. Although means are available for sound theoretical evaluation for determining optimum results for a given control loop, the necessary data on process characteristics is usually more difficult to obtain. Most controllers are designed with tuning adjustments, which make them suitable for a wide range of process requirements. Thus, identical controllers can be broadly applied, minimizing special training and the stocking of spare parts.

Satisfactory control of most process loops can be accomplished by employing the control actions described in 5.7.1 through 5.7.6. The precise execution of these actions may vary somewhat with the manufacturer, but the end results are similar.

5.7.1 ON/OFF CONTROL

On/off control is one in which the controller has two discrete values of output, fully on or fully off (see Figure 5-14). As the measured variable moves above and below set point, a cyclic full span output occurs. This action is useful for alarms and protective device actuation, as well as for automatic startup and shutdown of equipment. Limited applications exist in which the inherent cycling of a controlled variable is not objectionable. Where cycling must be restricted, but is acceptable, a differential gap action may be incorporated (see Figure 5-15).

5.7.2 PROPORTIONAL CONTROL

The output of a proportional controller is a continuous signal related to a multiple of its input. This multiple factor is called proportional gain or proportional band. Proportional gain is defined as the ratio of the change in output signal to the change in input signal. Proportional band is defined as the change in controller input signal, expressed as a percent of input span, required to produce a 100 percent change in output signal.

Proportional band may also be expressed in terms of proportional gain by the following relationship:

$$\text{Proportional band } (\%) = 100/\text{proportional gain}$$

The output of a proportional controller, as long as both

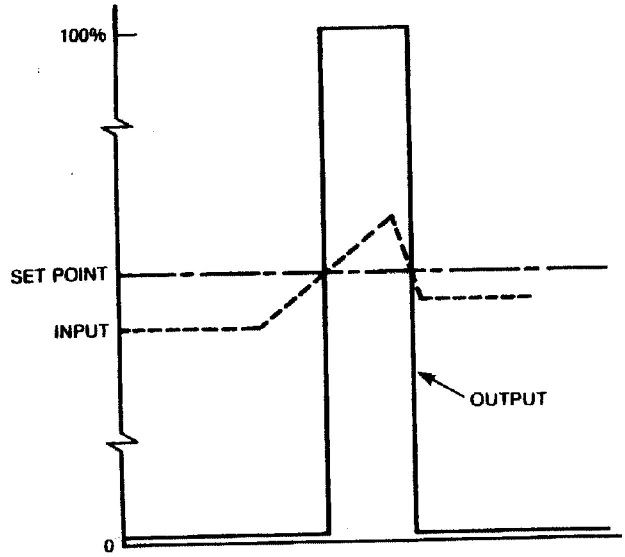


Figure 5-14—On/Off Control Open Loop Response

input and output are within their normal operating ranges, has a continous linear relationship with the input. Since this direct relationship exists between the input and output, this type of control action is not likely to maintain the process variable at a fixed set point. Consequently, this mode of control is acceptable only in processes where moderate offsets (deviations from set points) resulting from load changes, can be tolerated (see Figure 5-16).

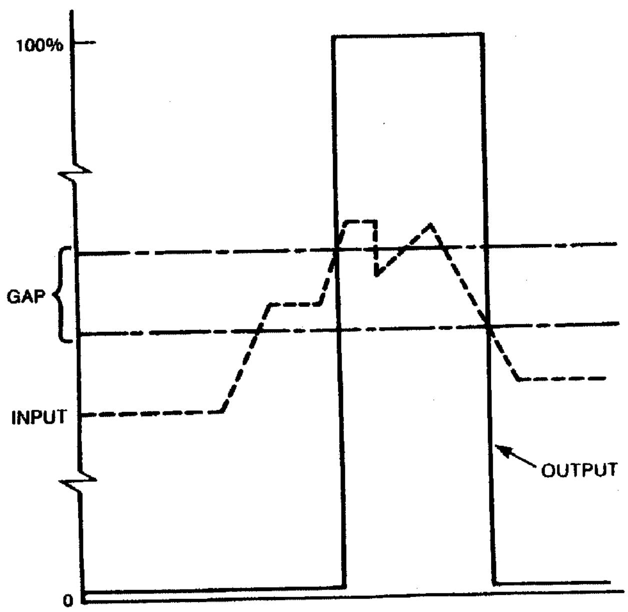


Figure 5-15—On/Off Differential Gap Control Open Loop Response

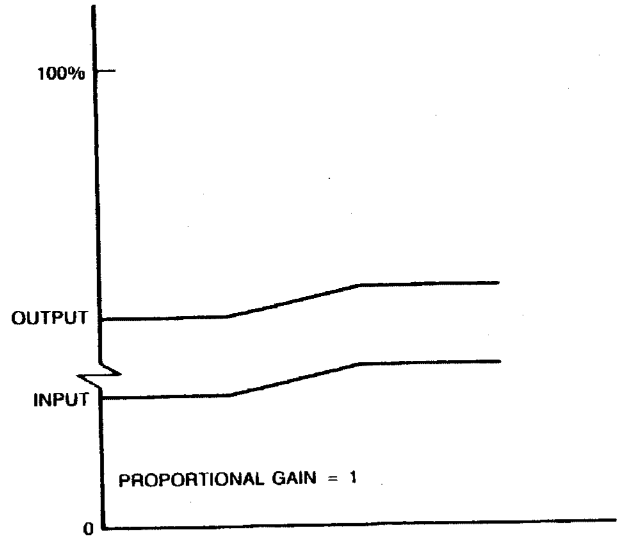


Figure 5-16—Proportional Action Open Loop Response

5.7.3 PROPORTIONAL PLUS INTEGRAL CONTROL

The addition of integral action (automatic reset) to a controller eliminates the offset that occurs with the proportional only mode. Integral action will cause the output to change as long as an error between the set point and the measured variable exists. Integral action will then cause the output of a controller to change automatically, resulting in a "zero error" under varying load conditions. Integral action is expressed as the number of repetitions of the proportional action per minute (repetitions per minute) (see Figure 5-17).

The proportional plus integral control action is more widely used in refinery practice than any other mode. It maintains the controlled variable at the set point under varying load conditions.

If the proportional plus integral controller is used in an intermittent operation or is normally off its set point, some difficulties may be experienced. Prolonged deviations on most proportional plus integral controllers will cause the output to drive to its limit (saturate). This limit may be beyond normal controller and valve operating values. This characteristic occurs particularly in batch operations, often resulting in unacceptable overshoot during startup. Most modern controllers offer some form of approach or anti-reset windup features, which serve to minimize or eliminate this effect.

Consult manufacturers' specifications concerning the availability and performance data on such features.

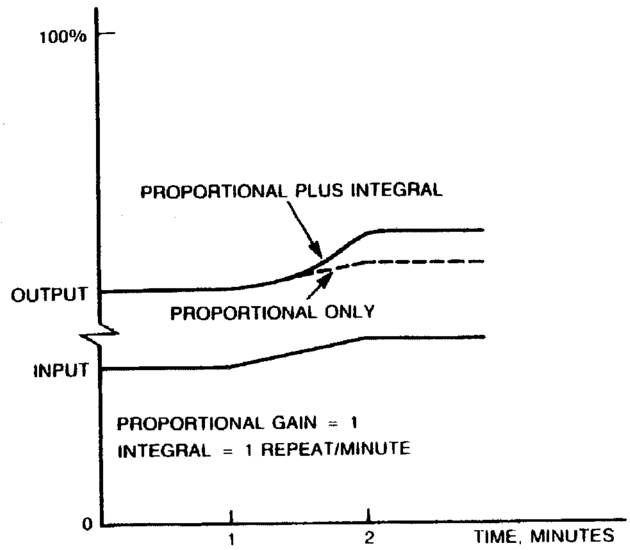


Figure 5-17—Proportional Plus Integral Action Open Loop Response

5.7.4 PROPORTIONAL PLUS DERIVATIVE CONTROL

Derivative action, when used with proportional control, causes the controller output to respond to the rate of change of the process variable (input). Proportional plus derivative control produces a lead in the controller output to compensate for the lag time in the process or measurement. The derivative response, measured in minutes, is the time that the derivative output leads the proportional output. Since the derivative controller output is a function of the rate of change of the input, it will be present only during the time the input changes value (see Figure 5-18).

This control is of value to minimize harmful or undesirable oscillations, or overshoot during startup operations. Processes with long lags and batch operations are examples of applications where proportional plus derivative control is useful. This control mode is not widely used in refinery operations.

5.7.5 PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL

Proportional plus integral plus derivative control is of value where the cumulative deviation from the set point must be kept to a minimum. Temperature applications on processes having long lags are typical examples. An indication of this control action is shown in Figure 5-19.

5.7.6 NONLINEAR CONTROL

If the relationship between the measured variable and the controlled variable is nonlinear, special algorithms or control action may be applied. One method is to add an error squared function to either the gain or integral action. The latter form is used when reset saturation is likely. Typical applications are pH control and sequential composition control, such as in chromatographic analysis.

Another type of nonlinear control utilizes a gap region where the control action is modified. The proportional plus

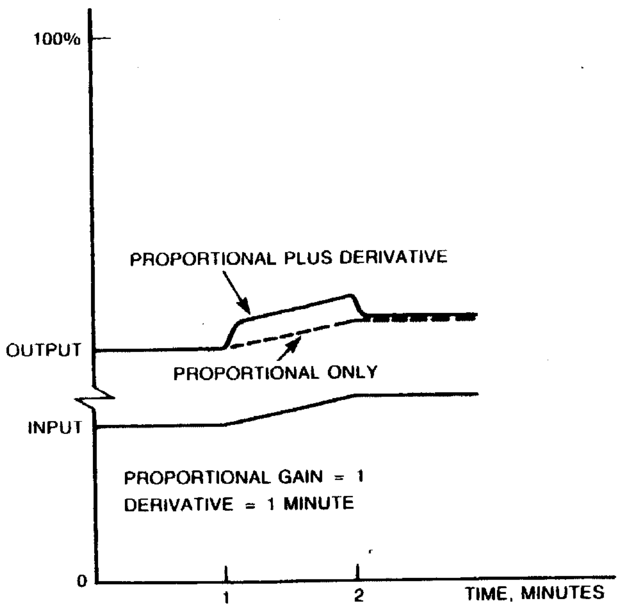


Figure 5-18—Proportional Plus Derivative Action Open Loop Response

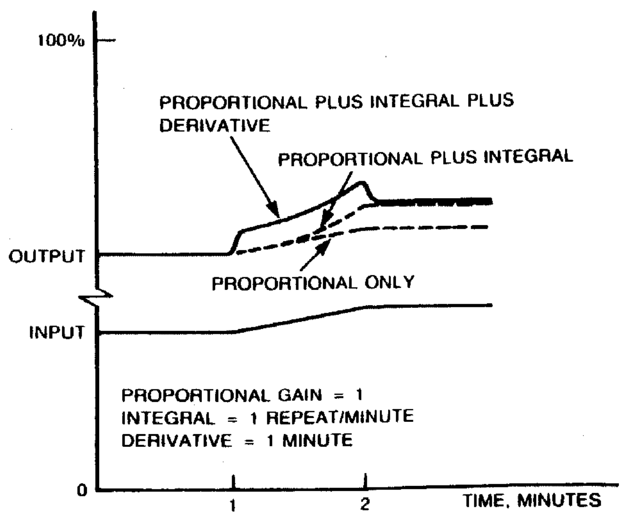


Figure 5-19—Proportional Plus Integral Plus Derivative Action Open Loop Response

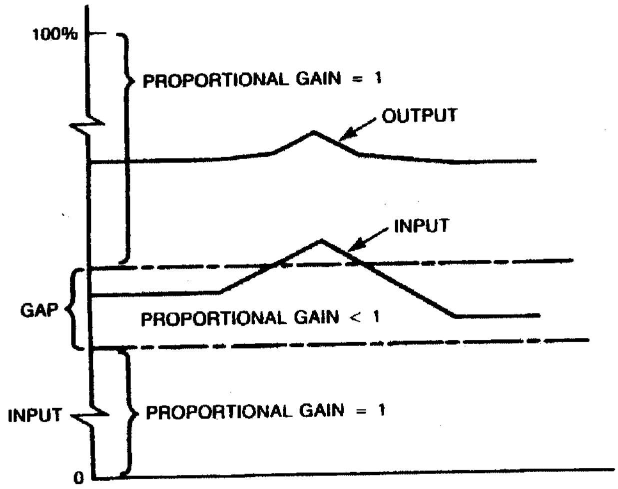


Figure 5-20—Nonlinear Control Open Loop Response

integral plus derivative action in the gap area is usually dampened or eliminated. A typical application of this control function is level control where the outflow needs to be smoothed because it feeds another process operation, such as a fractionator. Because of the geometric impact on process gain, nonlinear gap controllers are often used on horizontal vessels. Response curves are shown in Figure 5-20.

5.8 Typical Control Actions and Settings for Common Applications

5.8.1 FLOW

Proportional plus integral controllers are generally used for flow applications. Proportional gain settings of 0.4 to 0.7 and integral settings of 15 or greater repetitions per minute are common.

5.8.2 PRESSURE

In gas application, with large process volumes (series of large vessels, towers, and so forth) and in liquid applications in pipes or other small volumes, proportional gain settings for pressure control should be adjustable up to 2 and integral settings to approximately 3 to 5 repetitions per minute.

Conversely, in large liquid volume service and small volume gas service, proportional gain settings up to about 0.0002 and integral settings of no more than 2 repetitions per minute are usually necessary.

5.8.3 TEMPERATURE

Proportional plus integral plus derivative controllers are generally used for temperature applications although the amount of derivative action may be small. Controller adjustments are highly dependent on system configuration and control strategy.

5.8.4 LEVEL

Level controllers usually fall into two groups. Different gain requirements are necessary for each. This distinction between the groups is based on the effect of level change on other process variables. The difference is probably best illustrated by the following examples:

Example 1—Consider a fractionating tower from which the bottoms product flows to storage through a cooler where the flow is controlled by the level in the base of the tower and some variation in tower level is permissible. A proportional controller can be used with the proportional gain band set as high as is necessary to keep the level within acceptable limits. In this case, level changes will cause fluctuations in the flow rate until stabilization is reached but will not cause any harmful results, since process fluid is only going to storage.

Example 2—Next, consider the same conditions as Example 1 except that bottoms product is going as feed to another tower or through a heat exchanger preheating feed to the tower. If the control in the first example were used, the changes in flow rate of the bottoms product would cause upsets in other parts of the process. A level controller with a low proportional gain setting and a low reset rate will change bottoms product flow rates slowly and thus reduce, if not avoid, such upsets. For this case, the proportional gain should be adjustable down to at least 0.4.

Most unit processes have very little surge capacity other than change in level in process vessels designed for other purposes. To take advantage of available surge capacity, the proportional setting in control Examples 1 and 2 should be as low as practical. In cases where level is to be allowed to change to provide surge capacity, proportional plus integral controls are generally used. Proportional gain settings of 0.4 and integral settings of 0.1 repetitions per minute should be available.

5.9 Tuning Controllers

A complete treatise on tuning is beyond the scope of this publication. Various methods, some based on mathematical or graphical analysis, are available and will give satisfactory results. Manufacturers' literature should cover proper tuning techniques. Control performance depends on proper tuning. The more complex the process, the more critical tuning becomes.

In tuning controllers, consideration must be given to the cause of process upsets. Modern processes, with their many possible interactions between controllers, challenge the instrument technician's ability to recognize the source of upsets, the corrective measures needed, and the proper tuning of individual loops required to stabilize the process.

Figures 5-21 through 5-24 show the effects of various tuning adjustments.

5.10 Other Control Applications

5.10.1 CASCADE CONTROL

In a cascade control system the primary or master controller operates to maintain the controlled variable at a desired value by varying the set point to the secondary controller. The secondary controller, in response, operates the final control element so that the resulting value of the manipulated variable corrects the primary process.

Cascade control can reduce the effect of time constants in the loop (provided that the primary loop constant is of the order of three to five or more times the secondary loop constant) and prevent disturbances in the secondary loop from affecting the primary loop.

Figure 5-25 shows an application of cascade control. The objective is to control the tray temperature by regulating steam pressure in the reboiler. Without cascade control, any change in steam pressure will not be recognized until the actual tray temperature changes. The combined lags of this process make control difficult. To reduce the lag contribution of the reboiler, the steam pressure is monitored and becomes the secondary variable of the cascade loop. In this fashion the temperature controller "sets" the set point for the pressure controller.

The control actions for the individual controllers can be determined as described in 5.7 and 5.8. Both the primary and secondary controllers are usually provided with proportional plus integral action as a minimum. Derivative action may be required in the primary controller but is seldom used in the secondary.

It may be necessary to limit the amount of set point adjustment in the secondary controller.

5.10.2 RATIO CONTROL

Ratio control is the control of one process variable to maintain a fixed ratio with another process variable. The set point of the controlled variable is usually set by a device that multiplies the measured value of the uncontrolled (wild) variable by the desired ratio. While the uncontrolled variable might be completely controlled by some other independent loop, no attempt is made to control it in the ratio loop. Both signals should have the same characteristics (for example, both linear or both square root) (see Figure 5-26).

Ratio control applications requiring extremely wide ratios may present some problems; the required change in ratio may be greater than the ratio change available in the control mechanism. In this case, either one or both of the flow transmitter ranges may be changed to help achieve the desired ratio relationship.

5.10.3 FEEDFORWARD CONTROL

Feedforward control is defined as control action in which information concerning one or more conditions that can disturb the controlled variable is converted into corrective action to minimize deviations of the controlled variable.

Feedforward control is often used on control loops having long transfer lags where there is an appreciable dead time between the change in a process condition and the time that the effect of that change is detected by the control loop. The feedforward action has no effect on the set point of the controller which must remain constant, but does alter output to the control valve.

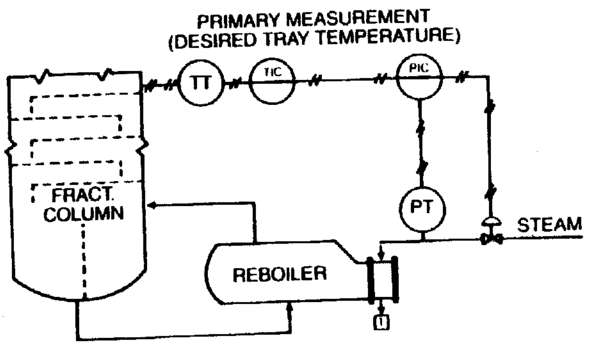
Figure 5-27 shows a simple schematic employing feedforward control of a heat exchanger for heating oil and using steam as the heating medium. Assuming the temperature and pressure of the steam entering the heat exchanger are held constant by other unrelated control loops, this control loop will perform well under conditions of constant flow rate of the oil through the exchanger. If the oil flow rate increases, the output signal of the oil flow transmitter causes an increase in the output of the oil temperature controller. This increase causes the steam valve to open further. If the change in steam valve position is not sufficient to hold the oil temperature at set point, the feedback controller will make the ultimate connection. Integral action of the temperature controller will then establish the controller output level at the higher value to hold control.

The feedforward signal must be adjusted (scaled) so that a change in the feedforward transmitter signal makes the correct contribution to the controller output signal.

5.10.4 OVERRIDE CONTROL

Override control is defined as a control system in which two or more process variables are related such that either can be controlled by the same manipulated variable. The first variable is controlled at a selected set point provided the second variable is on the "safe" side of the set point of the first variable. If the second variable approaches its set point, control is automatically transferred so that it will not go beyond the second set point. At the same time, the first variable falls away from its set point in a "safe" direction.

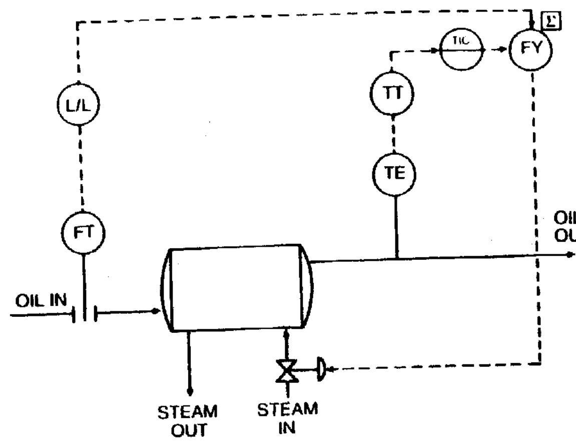
An example of a typical override control system is shown in Figure 5-28, which illustrates an automatic suction and discharge pressure control system for a pipeline pumping station. The throttled discharge pressure is controlled at a value, such as 100 pounds per square inch gage (690 kilopascals



Legend:
TT Temperature transmitter.
TIC Temperature indicating controller.
PIC Pressure indicting controller.
PT Pressure transmitter.

NOTE: Setting the pressure controller to a desired value reduces the effect of the reboiler time constant, and at the same time the pressure controller corrects for steam pressure variations.

Figure 5-25—Pneumatic-Type Cascade Control System

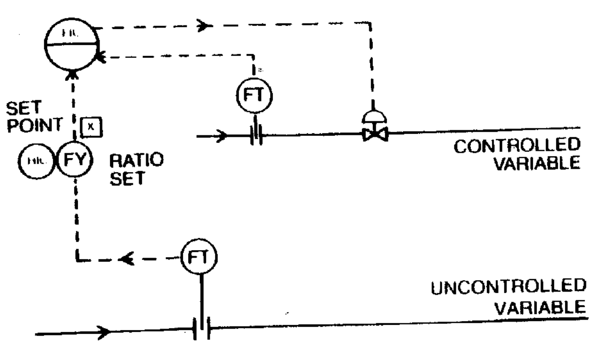


Legend:
FT Flow transmitter.
TT Temperature transmitter.
TE Temperature element.
TIC Temperature indicting controller.
FY Arithmetic unit adder.
L/L Lead/lag unit.

Figure 5-27—Schematic, Feedforward Control

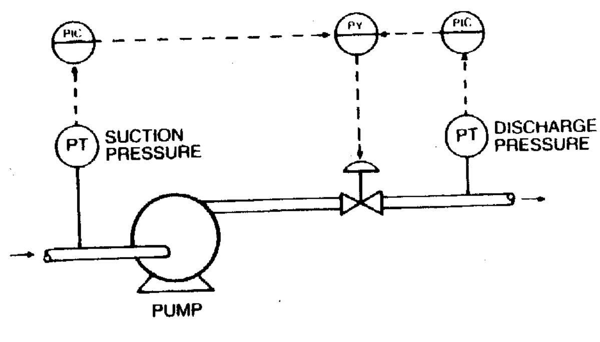
gage) provided that the suction pressure does not fall below 10 pounds per square inch gage (69 kilopascals gage). If suction pressure drops toward 10 pounds per square inch gage, control is automatically transferred to the suction pressure controller, which then operates the same valve. The suction pressure controller drops the discharge pressure to some value less than 100 pounds per square inch gage, but maintains 10 pounds per square inch gage at the pump suction. This condition will remain until discharge pressure rises to 100 pounds per square inch gage. Then control reverts back to the discharge pressure controller. Anti-reset windup must be provided.

The simplest form of override system is used when one or both of the controllers do not require automatic integral action. For example in the system shown in Figure 5-29, the controls maintain a constant discharge flow rate, so long as liquid in the tank is above some predetermined level. If the level does fall to this limit, the level controller overrides the flow controller, limiting the flow rate as required to prevent further drop in the level. The level controller has



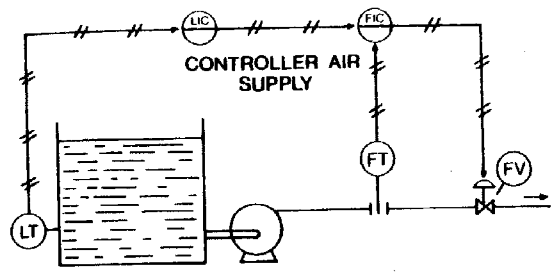
Legend:
FIC Flow indicating controller.
HIC Hand indicating controller.
FY Arithmetic unit ratio set.
FT Flow transmitter.

Figure 5-26—Ratio Control



Legend:
PIC Pressure indicating controller.
PT Pressure transmitter.
PY Signal selector.

Figure 5-28—Typical Override Control System



Legend:
LT Level transmitter.
LIC Level indicating controller.
FIC Flow indicating controller.
FT Flow transmitter.
FV Control valve.

Figure 5-29—Override Flow Control System

proportional-only action and the flow controller has proportional plus integral (reset) action.

The output of the level controller is merely used as the supply pressure to the flow controller. When level is above the set point, the level controller output is at its maximum and the flow controller operates conventionally. If the level falls near the set point, the level controller output decreases and deprives the flow controller of supply pressure so that it can retransmit only the pressure it receives. The level controller is therefore operating the valve. The integral system of the flow controller cannot "wind-up" because its air supply is limited. Consequently, transfer from one controller to the other is not accompanied by any upset to the valve signal.

If the integral controller were not arranged in this manner, its output would continue to rise until a saturation condition (wind-up) existed. At this point its output pressure would be at its maximum. Under these conditions, when the controller was required to assume control of the valve, a drastic overshoot would occur and would continue to occur until the controller could reduce the pressure to a value within its operating range. Wind-up can be avoided by feeding the selected output back to the integrating (reset) circuit of both controllers.

5.10.5 ADAPTIVE AND SELF-TUNING CONTROL

Many feedback loops are characterized by a nonlinear relationship between the measured variable and the controlled variable and operate over a wide range of conditions. When linear controllers are applied to such loops, tuning becomes a continuous problem. Tuning constants determined to work well at one set of operating conditions may generate subpar performance at another point in the operating range. Adaptive control is based on the concept that a control system could automatically adjust its parameters to maintain desired performance in spite of changing operating conditions. A special form of adaptive control is self-tuning control that dynamically updates a given controller's tuning constants (proportional, integral, and derivative) based on observed closed-loop performance.

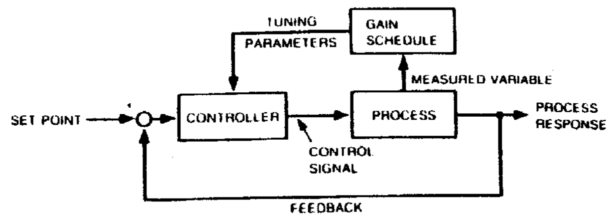


Figure 5-30—Gain Scheduling Type Adaptive Control

There are three approaches to implementing adaptive control: gain scheduling, model references, and autotuning. Gain scheduling involves using a measured process variable that exhibits a high correlation with changes in process dynamics (see Figure 5-30). As process conditions change from one operating region to another, controller tuning parameters change according to the schedule, which is a function of the variations in the measured process variable. Often a process flow rate is chosen for the measured variable since process time constants and delays are usually directly related to flow rates. This approach has been called gain scheduling because these systems originally were used to update only the gain term of the controller. Note that this technique is fixed in nature because there are no provisions to automatically update the schedule.

Another implementation of adaptive control is the model reference adaptive system as shown in Figure 5-31. With

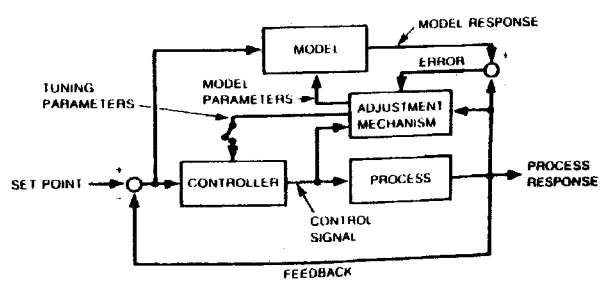


Figure 5-31—Model Reference Type Adaptive Control

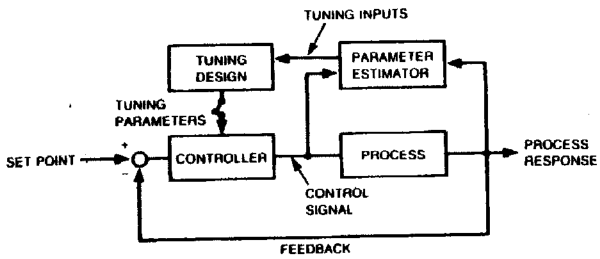


Figure 5-32—Automatic Tuning Type Adaptive Control

this technique, the adaptive control system uses disturbances to the process and forms a mathematical model based on the resulting process response. Tuning constants are determined using the model. This controller is self-tuning in that it uses process measurements based on applied disturbances and changing process conditions to modify its internal model and thereby adjust its parameters. In Figure 5-31 the controller block would always be active while the model and adjustment blocks would be under operator control.

A third adaptive control approach, sometimes referred to as auto-tuning, is shown in Figure 5-32. With this technique, process measurements are used to estimate parameters required for determining proper tuning constants. For example, the controller tuning block might use a Ziegler-Nichols tuning method for a proportional plus integral plus derivative controller. The parameter estimation block then would have the function of estimating the process ultimate gain and ultimate period which the Ziegler-Nichols method requires. This approach is similar to the model reference adaptive system case in that it uses disturbances to the process to implement the estimation block. It is self-tuning since it can continuously update itself by measuring process inputs and measurements, and it places the estimator and tuning blocks under operator control.

Previously, self-tuning controllers as described above, were used only in computer-based direct digital control systems. However, with the advent of microprocessors, single loop self-tuning proportional plus integral plus derivative controllers are now available.

5.10.6 SUPPLEMENTARY FUNCTIONS

Numerous functions are available, both as separate devices and as functional abilities resident in distributed control systems, that permit conditioning, modifying, or combining signals as inputs to or outputs from controllers. Those in general use are summing, multiplying, dividing, linearizing, signal characterizing, signal selecting (high or low), signal limiting (high or low), and lead/lag. The summer, multiplier, and divider perform simple arithmetic functions. Biasing and scaling are also possible with these devices. The linearizing function includes root extraction for flow signals and characterization for thermocouples and resistance temperature detectors. Signal characterization is often used on combustion controls and analyzer signals. Signal selectors provide an output equal to the higher or lower of two or more inputs and may be used to provide limit functions. A lead/lag unit provides either a signal delay or anticipation. Such a unit provides an output signal proportional to a single input with a time function superimposed and is often used in feedforward loops.

5.10.7 CONTROLLERS INTERFACING WITH COMPUTERS

There are two common types of basic computer control: supervisory control and direct digital control.

5.10.7.1 Supervisory Control (Set Point Control)

In this system, the computer, based on its internal program, repositions the set point of a loop. The process variable to the computer is obtained from field-mounted sensors. The calculated computer output, which represents the set-point variable, may be sent out as a contact closure, pulse height, pulse train, pulse duration, or a continous analog signal.

As shown in Figure 5-33, there usually is a feedback signal from the analog controller to the computer. This signal indicates that the set-point signal sent by the computer was received by the analog controller and was (or is being) executed.

There are two basic variations of analog controllers used in supervisory control. In the first, the computer drives the controller set point to the desired value by means of a stepping motor. An advantage of such systems is that on computer failure, the analog controller retains the last set-point

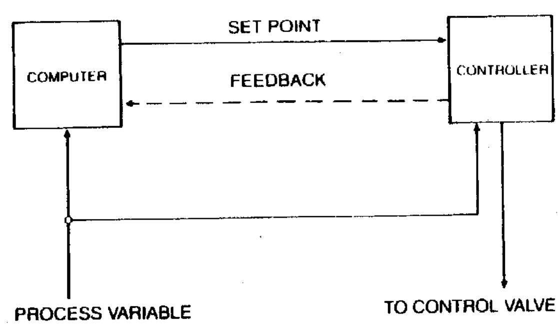


Figure 5-33—Block Diagram of Computer-Directed Set-Point System

value. Therefore, transfer from computer to local analog control is inherently bumpless and balanceless. A disadvantage of this system is the use of an electromechanical motor in each controller. In the second, the controller is set to computer set point and the computer output is fed to a solid state holding module. In case of computer failure, the last set-point value is held by the controller. Local set point is adjusted electronically by manipulating the holding module. This transfer is inherently balanceless and bumpless. In some cases, an additional local set point (that is, a discrete position) is employed.

5.10.7.2 Direct Digital Control

In direct digital control, the output signal from the computer is fed directly to the final control element. In the direct digital control mode, the computer receives process variable information and the internal program of the computer solves the control algorithm. Because the output of the direct digital control computer is always multiplexed, a holding module must be used to hold the computer output for the time period between consecutive scans. Analog instruments are often employed as backup for direct digital control systems. When direct digital control backup controllers or manual loading stations are used, the instrument itself is used as the holding module.

The action that will take place during computer outage depends on the type of analog backup station employed. When manual loading stations are used for analog backup, the manual station will hold the last value to the control element that was established by the computer. Over a period of time, the output of the station may drift. This output drift is usually defined by the manufacturer's specification (generally expressed in percent per hour). When the analog backups are automatic controllers, the simplest and most commonly used action is for the computer to revert to the hold mode of the controller. This hold mode is identical to the computer manual station. The instrument will hold the last output established by the computer. More sophisticated analog backup is available in which the instrument set point tracks the process variable or the computer-generated set point. When the computer fails, the instrument immediately assumes automatic control without process upset.

5.10.8 DIGITAL BLENDING SYSTEMS

Blending control systems have been used in the petroleum refining industry for many years. Many different types of systems are available ranging in style from self-contained, mechanically operated devices to electronic schemes utilizing sophisticated computer control that can optimize blends and control all product specifications. In the last few years however, blending systems that are referred to as digital blenders have been widely used in all types of refinery applications. A description of the operation of a digital blender with some references to applications and installation practices is provided in 5.10.8.1 through 5.10.8.5.

5.10.8.1 Definition

The term *digital* in control terminology is defined as discrete signal pulses. Accordingly a digital blender deals with discrete electrical pulses both in the measurement of flow signals, such as those derived from turbine meters, and in the control function by comparing set point pulses with measured pulses. Counting and generating pulses can be done very precisely with electronic equipment. A blender using such a system can produce higher accuracies of both measurement and control than can be achieved with analog systems.

5.10.8.2 Operation

In general, a blending system is a means of maintaining the proper volumetric ratio between individual components to be blended into a given finished product. In a digital blender the ratio of components is maintained by comparing a digital flow signal from each component stream to a given digital set point and actuating a final control element, such as a control valve, to maintain the desired relationship. Most digital blenders include features such as the ability to increase or decrease (or ramp) the total blend flow in accordance with a predetermined time schedule to ensure smooth stops and starts with no loss of blending accuracy. If the flow of any component should become limiting, then the total blend rate will be reduced to match the availability of that component. In some instances, a memory configuration is employed wherein the total blend rate remains constant and the deficiency of the component is stored in memory, to be corrected by the blender when the cause of the deficiency has been eliminated.

Digital blenders can offer temperature compensation of flowmeter outputs to produce blends on a net volume basis at a standard temperature. Resistance temperature probes are used to transmit the necessary signals to the blender.

On-line analyzers can be used to monitor and control specifications such as Reid vapor pressure and octane of gasoline blends (refer to RP 550, Part II, Section 8).[3] The addition rates of blend components are adjusted automatically until the required specification is met.

Push-button start of the blender is all that is required after the desired percentage of each component has been established and, if required, the total amount of blend has been set on a counter provided for this purpose. Automatic sequential starting and stopping of pumps and other auxiliary

[3]This reference is to a new fourth edition of Part II, Section 8, which is in preparation. For a more complete explanation, see the preface to this publication.

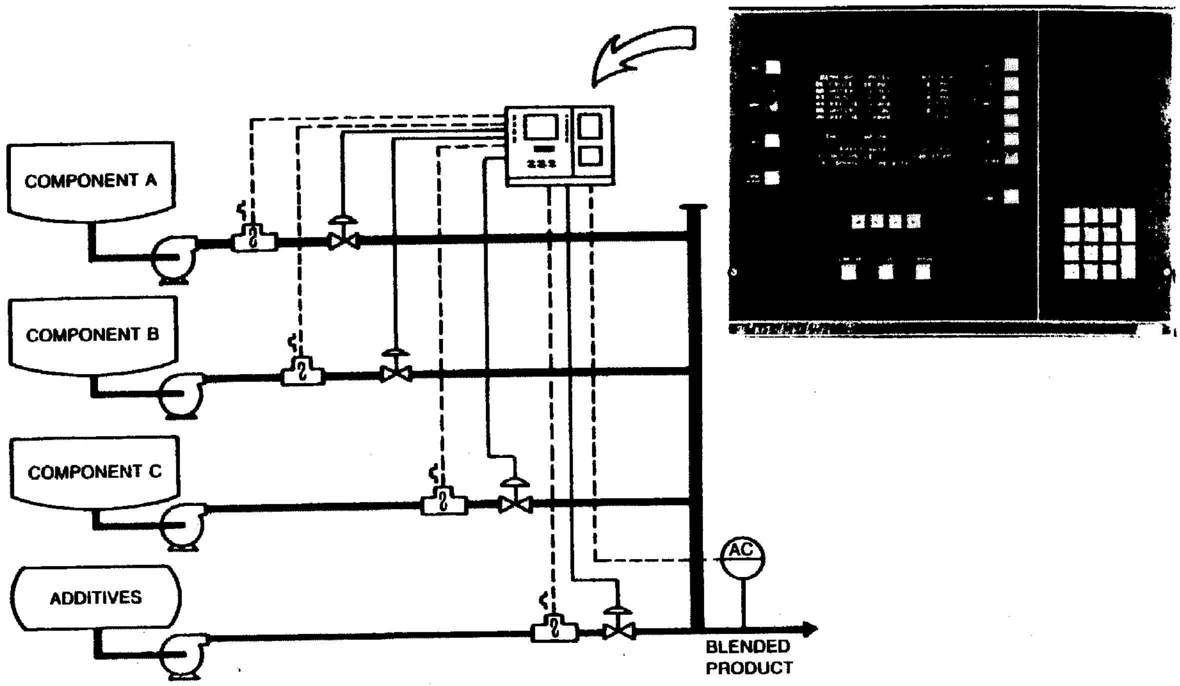


Figure 5-34—Microprocessor-Based Digital Blending System

devices can also be built into the system. Alarms or shutdown features are usually provided to notify the operator or stop the blend in the event that incorrect quantities are sustained for too long.

5.10.8.3 Typical Configuration

Most manufacturers of digital blending equipment use microprocessors as a basis for their systems. A typical arrangement is illustrated schematically in Figure 5-34. Such systems can accommodate up to 24 blended streams. They can be provided with an integral configuration panel to input the operating design. These systems can be custom designed by the user to suit his particular needs. The control strategies and settings, the arrangement of components and their scaling, alarm limits, and display labelling are entered by push button and can be easily changed or modified.

A significant feature of the microprocessor-based blender is its adaptability to a video display. A considerable amount of information can be presented to the operator at a central point through the appropriate manipulation of push buttons.

Whereas all the functions of a blender are incorporated in one package in the microprocessor-based system, other digital blenders may contain a separate master unit, a ratio unit, and component controller for each individual stream, as illustrated in Figure 5-35.

In any blending control system, there are primary settings for batch size and demand flow rate, as well as operating push buttons for alarm acknowledgment, master clear, and blend run and stop. Indication is provided for individual flow rates, demand flow rates, and totalizers for both measured and demand flows.

Digital blenders usually interface with on-line digital computer systems where optimizing, monitoring, scheduling, or dispatching are required. With such an arrangement, a more advanced control concept can be introduced, and the digital blender is able to continue to provide basic control in the event of computer failure.

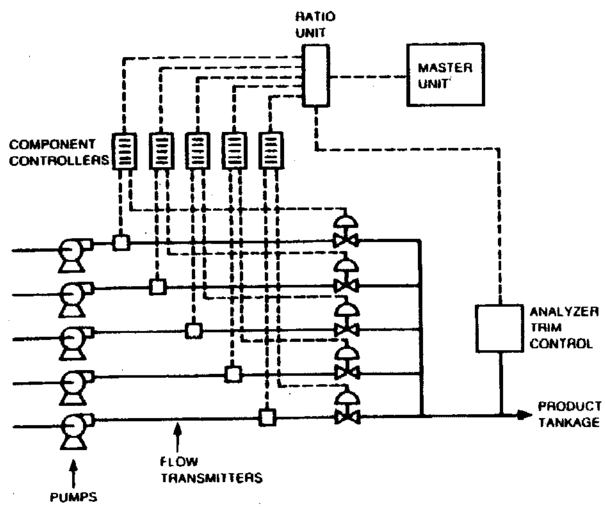


Figure 5-35—Typical Digital Blender System

5.10.8.4 Installation Requirements

The installation requirements of field equipment associated with blenders are the same as those for flowmeters (see RP 550, Part I, Section 1), control valves (RP 550, Part I, Section 6), and analyzers (RP 550, Part II).

The blender control panel is usually installed in a control room associated with other oil movement and storage activities and can be located quite a distance from the field blending equipment. Good wiring installation practices are important to ensure the security of transmitted signals and the accuracy of blends (see RP 550, Part I, Section 7).

Because of the electronic equipment involved, it is also necessary to ensure a good control room environment free of dust, corrosive gases, and high humidity (see RP 550, Part I, Section 12).

It is often desirable to locate the blender controls in a control center, which may be 2000 feet or more away from the field equipment. In such cases, a signal multiplexing system could be used to save wiring costs. A high-speed multiplexer system that provides separate continuous outputs for each remote input is preferred. Redundant data communication cables are recommended. The failure of such a system would not be problem free. But because of the batch nature of a blending system, failure would not produce the severity of upset that would occur in one of the main processing units. Even so, the main control loops should probably be hardwired.

5.10.8.5 Applications

Digital blending systems are used for in-line blending of final products directly into ships, transmission pipelines, or storage. Gasoline blending involving 15 to 20 components with automatic control of Reid vapor pressure, motor and research octane numbers, and boiling points is not uncommon. Fuel oil blending with corrections for viscosity, sulphur content, or flash point is being carried out in many refineries with digital blenders.

The modular concept of digital blenders lends itself to systems, involving both a few or many components, that may change in the future. Adding or deleting components can be accomplished simply and economically, especially with microprocessor-based systems.

5.11 Locating Single Loop Controllers

Controller location requires careful study. Controllers can be mounted (a) on the control room panels or racks either integral with, or detached from, a recording or indicating instrument; (b) near the point of measurement or control, or both; or (c) directly on the control valve actuator.

The number of possible instrument combinations makes it difficult to set up definite recommendations. However, the need for installation standards has led to the growth of a number of necessary working practices. Some of the more important ones are discussed in 5.11.1 through 5.11.6.

5.11.1 FACTORS AFFECTING CONTROLLER LOCATION

The following points (not listed in order of importance) should be considered when deciding on the location for a controller.

1. Convenience to operating personnel.
2. Convenience to maintenance personnel, accessibility for servicing, and frequency of servicing.
3. Installed cost, based on location.
4. Safety of personnel and equipment.
5. Vibration effects on equipment and performance.
6. Corrosion caused by the surrounding atmosphere and the process fluid.
7. Weatherproofing and winterizing, where necessary.
8. Explosionproofing, where required.
9. Protection from fire.
10. Accessibility in the event of fire.
11. Protection from mechanical damage.
12. Ambient temperature.
13. Radiation from the sun or hot equipment.
14. Company policy with respect to types of instruments purchased and their location.
15. Manpower availability.

5.11.2 TRANSMISSION LAGS

Process, measurement, and equipment response lags are common to all control systems. Electronic control systems are essentially free from transmission lags. However, multiplexing can produce time lags that should be considered. The following points are worthy of consideration for pneumatic controllers; although self-evident, they are often overlooked:

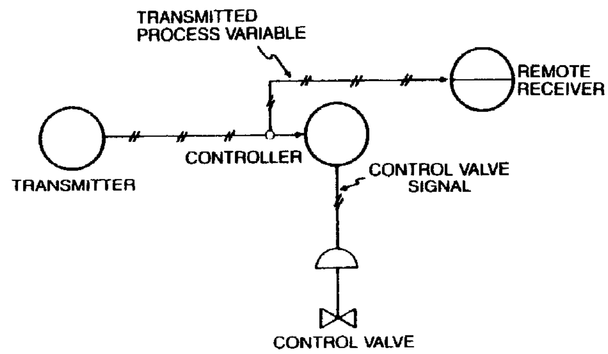
1. Lag is greater with longer tubing runs.
2. Lag is greater with very small tubing sizes (because of friction), as well as with very large tubing sizes (because of volume).
3. Lag is greater when air is flowing through the tubing to a large volume end device (for example, a valve actuator).
4. Lag is smaller when air is flowing through the tubing to a small volume end device (for example, a receiver bellows).

Table 5-1 compares lag time that should be expected with varying lengths of commonly used tubing. All lags were measured using an infinite source of air and a receiver bellows termination, so they should be considered minimum lag times.

Table 5-1—Comparison of Lags Expected in Varying Lengths of Tubing

Length of Run (feet)	Lag, in seconds			
	¼ Inch Tubing Percent Response		⅜ Inch Tubing Percent Response	
	63	95	63	95
25	0.18	0.32	—	—
50	0.3	0.6	0.18	0.28
100	0.65	1.2	0.37	0.65
200	1.5	2.9	0.9	1.7
500	4.5	7.8	2.5	4.7
1000	19	45	9.8	18

Source: Bradner, M., "Pneumatic Transmission Lag," ISA Paper 48-4-2, paper presented at the Instrument Society of America Annual Meeting, Foxboro Co., Foxboro, Massachusetts, 1948.



NOTE: The controller is of the receiver type, contains a manual set point, and may be indicating, recording, or blind. The remote receiver may be indicating or recording, or both, and is usually scaled to read out in the appropriate process variable units.

Figure 5-36—One-Tube System, Field Controller with Remote Receiver

Transmission lag can be reduced by proper controller location. Transmission lags of both transmitted and controlled air signals are affected by tubing size and length, by pilot capacity, and by terminal volume of the receiver. The situation is further complicated by the fact that a given lag that will introduce no control problems in one application may be entirely unsuitable in another.

5.11.3 CONSIDERATIONS IN MINIMIZING PNEUMATIC LAG

For those fast control applications where transmission lag is intolerable, it is suggested that a study be made of the overall requirements using Table 5-1 as a guide. Mounting the controllers adjacent to their valves will help considerably. Installing instruments with high-capacity air pilots is another method of reducing pneumatic lag. Consideration should also be given to changing tubing size, reducing terminal volume, or using booster relays (see RP 550, Part I, Section 7).

5.11.4 CENTRALIZING CONTROL STATIONS

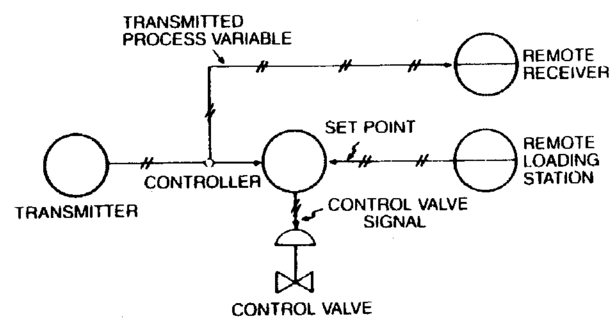
One major consideration affecting the location of the controller and control set point (remote or local) is operator convenience. This is of considerable importance because centralization of instruments usually results in more efficient and safer operation of process equipment. It is desirable to locate at a central point (usually in the control room) a sufficient number of instruments to permit control of all major process variables.

5.11.5 LOCALLY MOUNTED PNEUMATIC CONTROLLERS

Frequently, controllers are mounted locally because there is little justification for control room mounting or transmission lag must be reduced, or both. When reduction of lag time is the reason for local controller mounting, it is sometimes desirable to have a remote reading instrument or a remotely generated set point available in the control room. A number of combinations are shown in Figures 5-36 through 5-40.

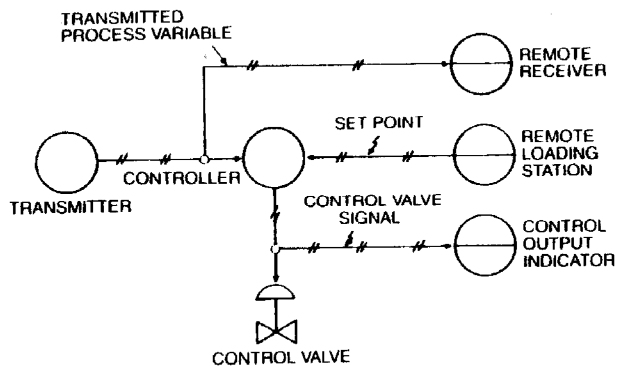
5.11.6 SPECIAL NOTES FOR ELECTRONIC CONTROL SYSTEMS

Input and output signals for electronic controllers are not completely standardized. For this reason, careful consideration of manufacturer's data is required, particularly when connecting various manufacturer's products together (see RP 550, Part I, Section 7). The following eight factors are especially important:



NOTE: The remote receiver and loading station may be separate items or combined into a single unit and may be indicating or recording, or both. The controller receives its set point from the remote loading station.

Figure 5-37—Two-Tube System, Field Controller with Remote Receiver and Loading Station



NOTE: Although the remote receiver, loading staton, and controller output indicator may be separate items as shown, they are most often combined into a single unit. Various combinatons of indicating and recording options may be applied.

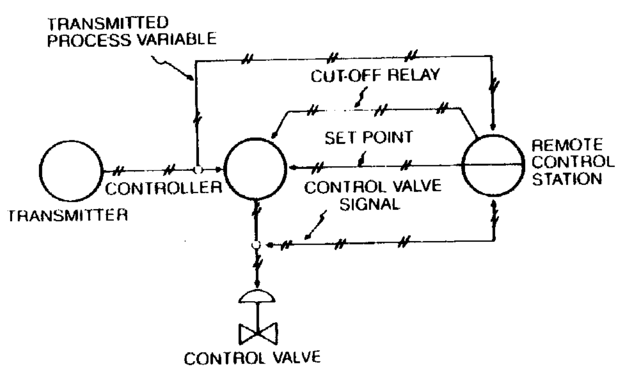
Figure 5-38—Three-Tube System, Field Controller with Remote Receiver, Loading Station, and Controller Output Indicator

1. Current output (most outputs are 4 to 20 milliamperes direct current) should be considered.
2. Maximum and minimum permissible load should be considered (refer to manufacturers' specifications).
3. Grounding requirements should be considered. Grounding of electronic controllers, as with most electronic equipment, is critical (consult manufacturers' literature). As a sound general rule, avoid grounding at more than a single point. Do not assume that panel boards are grounded. Run a solid earth ground.
4. Controller wiring should be kept away from power wiring, particularly any wiring subject to voltage surges, such as those resulting from switching of lights, motors, and so forth (see RP 550, Part I, Section 7).
5. Some electronic devices require the use of shielded cable.
6. Moisture, conductive dust, or corrosive atmospheres may degrade the reliability and performance of electronic instruments. The ambient temperature limit of most electronic instruments is commonly 40–120 F (5–50 C). (Consult manufacturer's specifications for exact limits, as well as performance influences.)
7. If an intrinsically safe installation is desired, additional precautions are required.
8. Power supplies should be considered. (Refer to RP 550, Part I, Section 11 for information on power supplies.)

5.12 Mounting

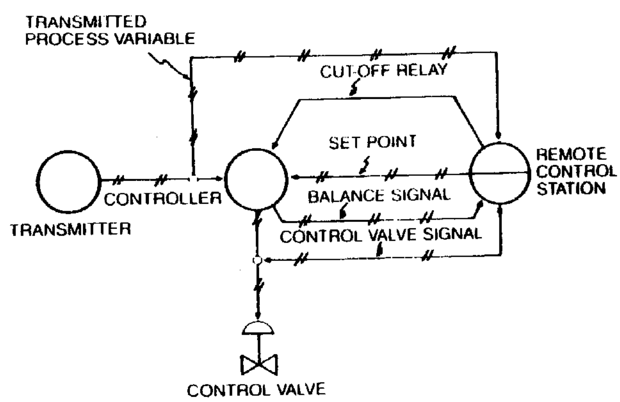
Some single loop controllers are mounted on or within recording or indicating instruments; others are installed separately. Methods of mounting local controllers include flush, surface bracket, and yoke. Also some controllers can be mounted on the valve yoke or actuator of a control valve. It is beyond the scope of this section to cover the mounting of instruments on panel boards. This topic is discussed in RP 550, Part I, Section 12.

The principal considerations in mounting are rigidity, accessibility for service or maintenance, freedom from excessive temperatures, design of the instrument, fire protection, and the desirability of freedom from vibration and mechanical damage. Normally, the requirement for vibration-



NOTE: The remote control station, consisting of a process variable receiver, set point adjusting device, control valve indicator, and transfer switch, is usually installed on an instrument panel in a centralized control room. Various combinations of indicating and recording options may be applied. In a four-tube system, the transfer switch provides the capability for bumpless transfer of the remote controller to affect automatic or manual operation of the valve.

Figure 5-39—Four-Tube System, Field Controller with Remote Control Station



NOTE: The remote control station, consisting of a process variable receiver, set point adjusting device, control valve indicator, and transfer switch, is usually installed in a centralized control room. Various combinations of indicating and recording options may be applied. The five-tube system, using the balance signal, provides a simpler method of bumpless transfer of the remote controller.

Figure 5-40—Five-Tube System, Field Controller with Remote Control Station

free mounting precludes mounting a controller on a control valve. However, there are some controllers designed for this service.

5.13 Miscellaneous Control Requirements

Most pneumatic controllers are furnished with automatic/manual switching. Also available, on certain pneumatic instruments, are provisions for bypass that will permit the removal of the automatic or the manual section for service or replacement.

5.13.1 BYPASS FACILITIES (PNEUMATIC)

Bypass facilities should be furnished with every controller used on major process variables. This facility allows remote manual control in the event of unsatisfactory operation or failure of the automatic control. Inasmuch as switches arranged for bumpless transfer are available in a number of combinations, the following practices are recommended for their selection:

1. Two- or three-position transfer switches and regulators should be supplied for all temperature controllers, critical control applications, and all controllers used in cascade control systems.
2. For other applications requiring bypass facilities, two-position transfer switches and regulators are satisfactory.
3. Local controllers do not necessarily require bypass systems.

5.13.2 BYPASS FACILITIES (ELECTRONIC)

Most electronic controllers include provision for automatic/manual switching. Manual control provisions fall into two general categories: (a) hard manual, where a knob operated direct current generator provides the manual output signal and (b) soft manual, where push buttons or momentary contact switches provide a signal, which is memorized by a special module providing the manual output signal.

Hard manual systems generally permit switching from manual to automatic without changing the output but require an intermediate balancing operation to avoid upset when switching from automatic to manual.

Soft manual systems avoid all balancing operations. Very minor drifting of manual output is inherent in some systems due to the use of the memory module. In others, no drift is experienced. Consult manufacturers' specifications for details.

5.14 Acceptance Testing and Checkout

5.14.1 SINGLE LOOP CONTROLLERS

Acceptance testing of single loop controllers allows for a systematic, repetitive approach. Procedures are further aided by the availability of numerous detailed guides and manufacturer's documentation. Reference to a combination of those publications is encouraged since they provide a step by step checkout procedure beyond the scope of this manual.

On instrumentation packages involving panel mounted single loop controllers in a high density configuration, checkout at the panel manufacturer's site should always be required (see RP 550, Part I, Section 12). Although such checkouts do not eliminate the necessity of an acceptance test at the plant site, corrective measures are often more easily implemented at the panel manufacturer's site. Detection and correction of piping and wiring errors is especially important in the panel checkout procedures.

5.14.1.1 On-Site Procedures

1. Perform a critical visual inspection for damage that may have occurred during shipment or installation. Check connections for accuracy and obvious irregularities, such as loose piping or tubing fittings, loose wiring, and improperly secured printed circuit boards. Remove all shipping stops, supports, or packing materials.
2. Inspect each instrument data plate to certify that it conforms to the requisitions and documentation.
3. Determine, particularly on field mounted controllers, that controllers have been properly mounted in an appropriate location. Inspect the location considering accessibility for maintenance and operation, and ensure proper environmental protection.
4. Following the manufacturers instruction manual carefully, check each controller in the following general manner: (Note that at the inspector's option, these checks may be performed with the controller in place or at a bench location.)
   a. Apply a suitable source of air and/or electrical power to the appropriate connections.
   b. Provide an appropriate variable input signal to simulate the process variable.
   c. Connect the output to a suitably scaled electronic test meter or via a capacity chamber to a manometer or test gage.
   d. Using the manufacturer's instruction manual as a guide, carry out a complete operational check making necessary adjustments to demonstrate functions such as proper alignment and tracking; control modes (that is proportional, integral, or derivative); direct and reverse action; auto/manual/remote transfer; and calibration.
   e. On receiver controllers, an additional or optional "closed loop" checking method may be used. For this test, the controller is set at reverse action. Its output is then connected to its input through an electronic or pneumatic resistance capacitance network to behave like a fast acting control loop. Again, paying particular attention to the

manufacturer's instructions, all functions of the controller can be checked under simulated process conditions.

5. Perform a complete loop test, prior to start up, with the controller in place.

6. Establish a record for each instrument and record the test results. Work sheets and guides for instrument records are available from a number of sources. The format should include:

a. Manufacturer, model, and serial number.
b. Date of acceptance test.
c. Controller type.
d. Condition of instrument, as found.
e. Corrective action taken.
f. Condition of instrument, as left.
g. Calibration data.
h. Recommendation for further action or disposition.

5.14.1.2 Equipment Required

A common but not exclusive list of test equipment includes:

1. Dead weight tester.
2. Mercury manometer.
3. High accuracy pneumatic test gage.
4. Digital volt-ohm meter.
5. Special maintenance and test equipment prescribed and/or offered by the manufacturer.

5.14.2 DISTRIBUTED CONTROL SYSTEMS

Distributed control systems are by nature highly interdependent since they utilize various combinations of shared functions. Most common among these shared functions are: operator interface, control algorithms, and data transmission. Further, such systems allow for a higher level of control system sophistication and collectively present a different task to acceptance testing and checkout personnel.

As part of a system package, manufacturers should be required to include a witnessed acceptance and checkout test at their factory prior to shipment. These tests should have a written procedure and should be designed to exercise the system fully to demonstrate operation and performance, utilizing simulated field inputs and observing outputs. In some cases, process models are generated to provide some measure of real time responses.

Attendance and participation at factory checkouts can provide the user with valuable experience which can be carried over to establishing a valid field checkout procedure. The same personnel should be involved in both tests.

Because of the wide variety of equipment, a detailed acceptance test and checkout procedure is beyond the scope of this publication. However, a general outline will provide a means of direction when viewed in concert with the manufacturer's instructive material. The primary purpose of acceptance testing is to ensure that the complete hardware/software system will perform according to the prescribed specifications. Typical objectives are:

1. To verify the reliability of the system and its components by conducting a 48-hour minimum operating test. The entire system must run, performing its functions, for 48 continuous hours without failures. Some companies require a 100-hour test. This test provides performance data and eliminates many of the incipient failures of electronic equipment.
2. To verify the performance of all components in the system configuration, with all units fully powered and enclosed in proper housings or cabinets.
3. To verify the presence of personnel safety precautions in compliance with industry standards and applicable codes.
4. To ensure proper performance of operator functions.
5. To acquire data input and generate proper outputs (on a simulated basis initially and with actual process signals finally).
6. To execute and verify any customized configurations (hardware and/or software).
7. To generate hard copy logs or reports and video displays, as required.

5.14.2.1 On-Site Procedures

1. Perform a critical visual inspection for damage that may have occurred during shipment or installation. Parts should be inspected for proper placement and secured connections. Obvious damage or other irregularities should be corrected before applying system power.
2. Inspect the location where the equipment is installed to determine that a proper environment has been provided. Consider ambient temperature, humidity, excessive dust, and the presence of a corrosive atmosphere. In new installations especially, ensure that the equipment is protected from temporary construction hazards. Manufacturer's recommendations shall be considered as a minimum standard. Refer to RP 550, Part I, Section 12.
3. Prior to connecting field signals, apply appropriate line voltage to the system and perform a system power and grounding check. Refer to RP 550, Part I, Sections 7 and 11.
4. Repeat the system power and grounding check with simulated full system load.
5. If appropriate, determine the susceptibility to radio frequency interference or any other electromagnetic interference to ensure that no operating problem may occur.
6. Where applicable, follow closely the manufacturer's or consultant's instructions concerning the implementation of hardware and software diagnostic routines. Diagnostics come in various forms such as tapes, disks, test components, and keyboard entries, and provide a valid test of various subsystems. Typically, diagnostic routines are provided for:

a. Central processing unit.
b. Operator's panel.
c. Data transmission link.
d. Process input/output.
e. Memory.

7. Load the software package and use it to exercise the various other peripheral devices provided, such as:
a. Discrete loop controllers, calculators, and function generators (analog or digital).
b. Multiloop controllers.
c. Trend recorders, line printers, and teletypes.
d. Cathode ray tubes.

As has been the case in conventional control systems, accurate records are essential to the timely completion of these tasks. Appropriate work sheets for such records are often provided by the consultant or manufacturer. In their absence, however, the user must devise such a format.

In light of the vast variety of direct digital or hybrid systems available, attempts to further detail the acceptance testing procedure would be of questionable value. Close coordination with the supplier is advisable.

5.14.2.2 Equipment Required

A common but not exclusive list of test equipment includes:

1. Oscilloscope.
2. Digital voltmeter.
3. Special maintenance test equipment prescribed and/or offered by the manufacturer.
4. Diagnostic tapes, disks, and test components, as provided with the system.