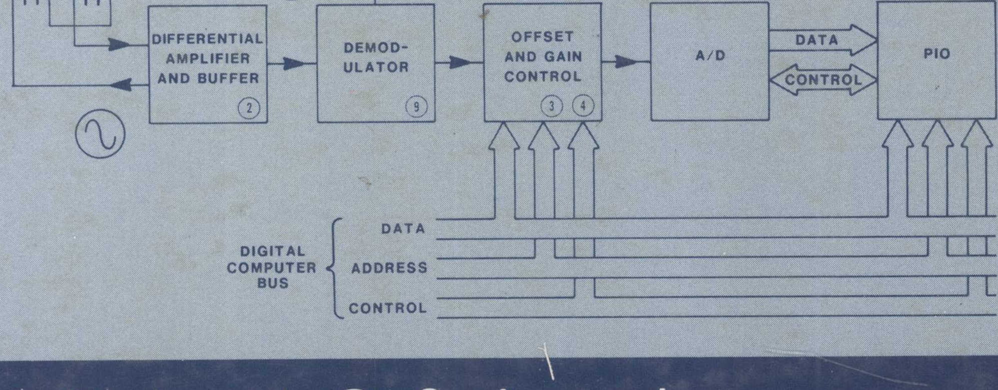
TRANSDUCER INTERFACING

Signal Conditioning for Process Control



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Preface

In today's world, it is necessary to measure everything; all mechanical things, all the toys we play with, and all the functions involved with communication are carefully monitored. We are conscious of every parameter of the weather, of the vital phenomena of the body, and all other physical happenings that prevent us from, or impede our progress as, world builders, shakers, and movers. We check the quantity and quality of everything from sunshine to earthquakes. We have also learned to live with the computer, whose task it is to keep track of all these wonderful things we have become accustomed to. The computer performs as our personal mathematician, our statistician, organizer, designer, and library. Now the microprocessor as well controls this work, in order that we may continue to live in our accustomed manner.

We are truly living in an awesome time. We have the ability to measure and control many of the things that effect our lives. Unfortunately however, physical parameters all have different characteristics. We cannot feed our computer a rain storm and expect it to control the valves of a flood control basin. The vital signs must first be measured. Measurements must then be converted to a language that the computer can understand, since the computer has limited ability to operate by external variables. All the things we measure are not always consistent, and, to make things worse, are in many different forms.

It is the purpose of this book then, to bridge the gap between the output of the transducer and the microprocessor (computer). This gap is called *signal conditioning*. Signal conditioning is the method by which a transducer's analog (variable) output is converted to a form that the computer can both understand and deal with. The first chapter of the book is a review for some readers on the fundamentals of control and control systems. Chapter two provides the essentials of measurement, including the features that have evolved with process control. Chapter three includes descriptions of transducers, sensors, and detector elements. This chapter is relevant for an understanding of the entire book. Chapters four and five provide the fundamentals of analog and digital signal conditioners. Chapter six describes the methods of conditioning signals derived from transducers to an analog level convertible to digital language, and chapter seven provides an interface between the computer and the control device. Finally, chapter eight is designed to tie chapters six and seven together, integrating the total control system. The appendix is a library of common circuits used within the signal conditioning chapters.

It has been assumed that the reader has some background in electronics exists in the reader. A knowledge of transducers and computers is also helpful for understanding. It is hoped that the experienced designer will utilize the chapters on signal conditioning as a reference and ''idea bank,'' and that new people in the field will use the book to gain an understanding of measurement and control. The material has been presented in as simple a form as possible to fulfill the particular needs of the experienced and the aspiring.

A special thank you is given to Bob Eisenhauer, Automatic Control Systems Electronic Supervisor, Hydraulic Research Textron, Valencia, California, who provided a depth of signal conditioning expertise derived from experience. He was also gracious enough to edit the manuscript. And as usual, appreciation is given to my artist JoAnne Bline, and my word processor operator Diana Sunker, for their excellent work under pressure. A final tribute is given to the multitudes of manufacturers of transducers, and to the hundreds of engineers that I have had the privilege of working with over the years.

Robert G. Seippel

Contents

1

Process Control Defined

Process control is a means by which a quantity of interest within a machine or mechanism is controlled, maintained, or altered. The process that is controlled may be a function of the machine or a product produced by the machine.

Obviously, the reader will have to make judgment of these statements. However, when a simple function such as the heating system in a home is suggested, not much judgment is required. The homeowner sets the thermostat for the desired temperature. When the room air temperature drops to that set point, the furnace turns on automatically. The air warms to the set point, as sensed by the thermometer. The furnace turns off at the set point. Temperature has been regulated. A simple *single-variable* control process has been defined.

We are all familiar with the automobile. The driver of an automobile determines the route and selectively modifies the speed and acceleration. Speed and acceleration are changed by stepping on the accelerator. The stronger the force, the greater the acceleration. The accelerator, through linkage, the carburetor, and all the other engine systems, controls the speed and acceleration of the automobile. The multiple variables of auto weight, road conditions, hills and valleys, and so on, are all controlled simultaneously by the operator. The speedometer and odometer monitor the speed, acceleration, and distance, and fuel quantity being consumed is indicated by the fuel gage. The cooling system stabilizes the engine temperature. The electric system coordinates power for lights, engine operation, radio, inside heater and defroster, and so on. The brake system allows slowdown and stopping. The automobile is a *multivariable control process*.

In the machining industry, manufacturing is done in stages or sets of operations that lead to an end product. In the farming industry, processes are made at different intervals, which leads to the controlled growth of food crops. Process control of farm products is not as exact as those of a machine shop, for the variables of weather are more difficult to maintain or alter.

Operating a radio is a process control. We turn the radio on, tune the dial to a station, and then fine-tune it to isolate the frequency of the signal being transmitted. The designer of the radio had in mind a common thought involving efficiency and fidelity which provides the process with the variable called quality. The process controls within the radio work toward this goal.

The concepts of the control system, process control, and processes being controlled are all intertwined. The purpose of this chapter is to separate and evaluate the principles of process control. The elements will be organized into simple, understandable segments.

To begin the chapter, a simple closed-loop system and open-loop system are illustrated. This is followed by a description of several varieties of process, including single, double, compound, and cascade processes. Let us consider a simple liquid control system.

FUNDAMENTAL CONTROL SYSTEM

Figure 1–1 illustrates a fundamental liquid control system. This system is used in large reservoirs as well as small water control areas. We have simplified the system to achieve understanding.

In this system the *process* includes the input piping, the tank, the output piping, and the liquid. The liquid level is constantly changing, and is thus called

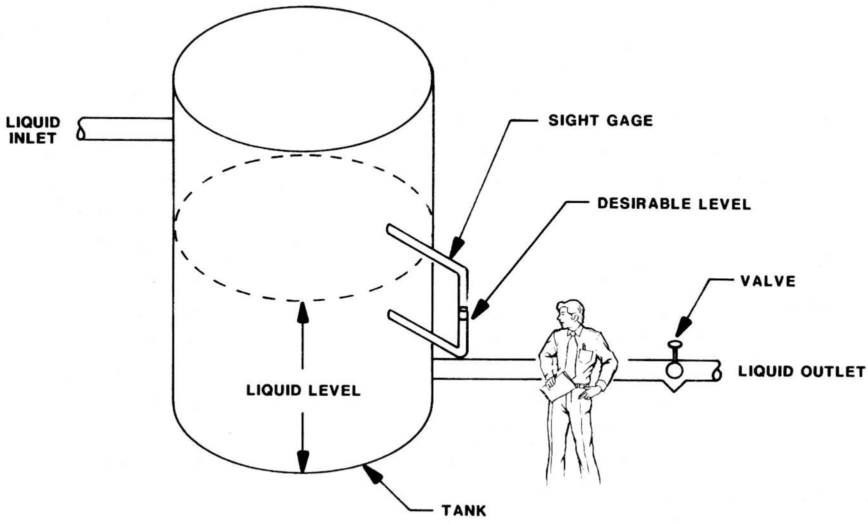

Figure 1–1 FUNDAMENTAL CONTROL SYSTEM

a *dynamic variable*. We can control this level; therefore, the variable is a controlled variable. A person is the *controller*. The valve is the control element. The sight gage is the *measurement device*. The measurement device is marked at a predetermined desirable level called a set point. The set point is reached when the level of the liquid reaches the set point.

Liquid is poured into the tank at an uncontrolled rate and amount. If we were to leave the system without control, it would probably fill to overflow. Lack of control is the case in an *unregulated* or *open-loop* system. In a regulated system we attempt to control the set point as closely as we can by *feedback*.

The controller, a person in this case, is constantly *evaluating* the relationship between the set point and the actual liquid level. When the sight gage indicates to the controller that the liquid level has risen above the set point, the person opens the valve (control element). The valve provides an outlet for the excess liquid. When the level of liquid falls below the set point in the tank, the person closes the valve.

Information from the sight gage was picked up by the controller's eyes; in turn, a *feedback* was sent to the valve via the controller to *regulate* the level of liquid. The *regulated system* is a closed-loop process. This simple single-variable process has all the functions of a more complex system. The functions for closed-loop regulation are as follows:

1. Measurement of the controlled variable
2. Comparison of the controlled variable and a set point
3. Determining the amount of difference (error) between the controlled variable and the set point
4. Directing a control element to remove the error
5. Feeding back a correction to the process to return the variable to the set point

In order that the process control be operative and continuous, these functions must be accomplished in sequence and repetitively.

Closed-Loop Control System

The block diagram in Figure 1–2 is of a closed process control loop. The components of the closed loop are the controller, the control element, the process, and measurement. This loop compares with the pictorial process control system presented in Figure 1–1.

The controller consists of an error detector and a signal processor. The error detector is simply a summing point (from electronics) of the set point and feedback signals. The output of the error detector is an error signal.

$$C_E = C_{SP} - C_{FB}$$

where

$$C_E = \text{controlled variable error signal}$$

$$C_{SP} = \text{controlled variable set point}$$

$$C_{FB} = \text{controlled variable feedback}$$

The signal processor performs the function of comparing the desired value of the dynamic variable (*set point*) with the measured value of the dynamic variable (*feedback*). The signal processor further determines what action should be taken. This action is relayed in some command form to the control element. The control element provides the drive to bring the controlled variable back to its set point. The control element causes the process to be modified. Meanwhile, the measurement element monitors this change. The monitored signal is a measurement of the controlled variable. This value is returned to the error detector as a feedback signal. In the error detector it is again compared with the set point to achieve an error signal. This process will continue until there is no error.

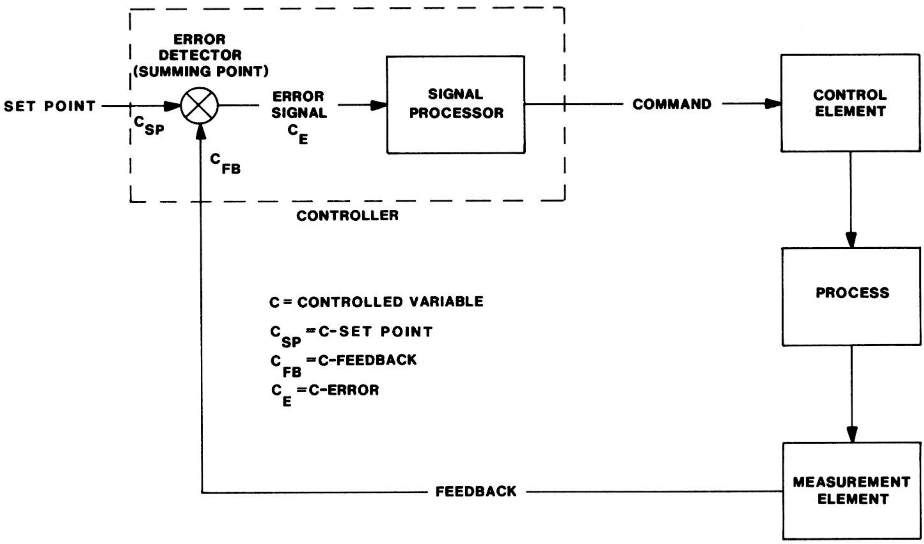

Figure 1–2 CLOSED-LOOP CONTROL SYSTEM

Open-Loop Control System

An open-loop control system is represented pictorially in Figure 1–3. The liquid level is the dynamic variable. Neither the rate and amount of flow into the tank nor the liquid output are controlled. It may be assumed that the tank will

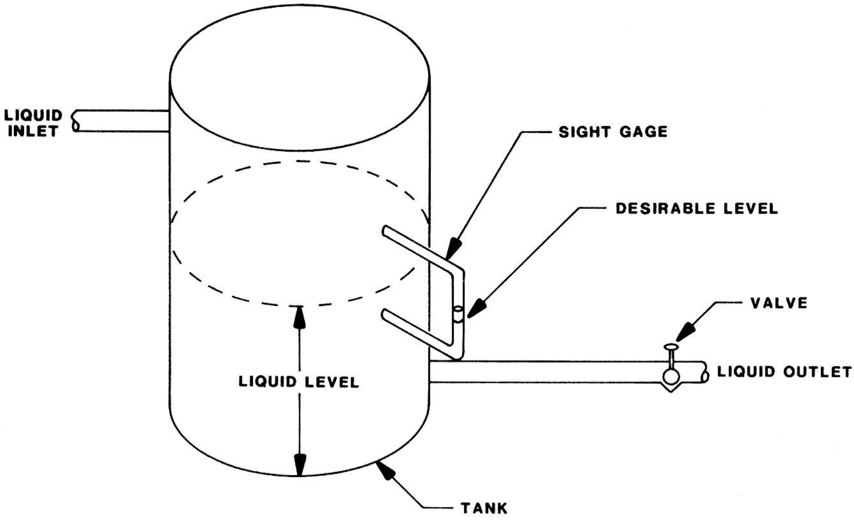

Figure 1–3 OPEN-LOOP CONTROL SYSTEM

overflow if too much liquid is placed in the input. Without feedback from an operator (controller) the process is running *open loop*. There is no regulation. The liquid level is not being maintained. An example of an open-loop system is a reservoir which overflows into a catch basin when it overfills. Open-loop systems are desirable when an output remains constant for a constant input. If external conditions remain unchanged, open loop is a feasible operation.

THE PROCESS

The word *process* means a particular method of doing something, generally involving a number of steps or operations. In a machine shop, a length of steel round stock is machined in several different operations to produce an end product. The end product will have specific uses and will conform to specifications of structure. The end product is a result of the total operative steps taken.

In a bakery, flour, yeast, water, and other additives are mixed, made into dough, allowed to rise, and baked under controlled conditions. The result is bread which has the properties desired by consumers.

Flight of an aircraft is dependent on a variety of conditions. Just to keep it aloft, several dynamic variables, including angle of attack, thrust, lift, and drag, are carefully coordinated. Variables such as altitude, airspeed, and wind velocity also come into play. Most of the variables may be regulated; some cannot be. It is also realistic to say that all the parameters of flight are interrelated and must be acted on all the time.

It is desirable, if not mandatory, to control all dynamic variables. Some are individual and must be acted on alone. These are called single-variable processes. If many elements are involved, the process is called a multivariable process.

There are a multiple of process types. The type is dependent on the job to be accomplished. Using the tank of liquid as a medium, we shall discuss, in general terms, the following processes:

1. Single-variable process
2. Two single-variable processes with interacting functions
3. Two dependent single-variable processes
4. Compound-variable process
5. Cascade process

Single-Variable Process

The single-variable process is one that has only one element to be controlled. An example of this is shown in Figure 1–4. The process under control is the level of liquid in the tank. A *liquid-level sensor* is placed in the tank and set at a desired level. As the liquid input increases, the level of the liquid in the tank increases to the set point. When the set point is reached, the controller sends instructions to open the control valve. The instructions continue until the level of the liquid has been lowered to a safe or desirable level. Continuous information from the sensor to the controller may be provided for constant level information and continuous error correction. Switching action by the sensor is also acceptable for some applications.

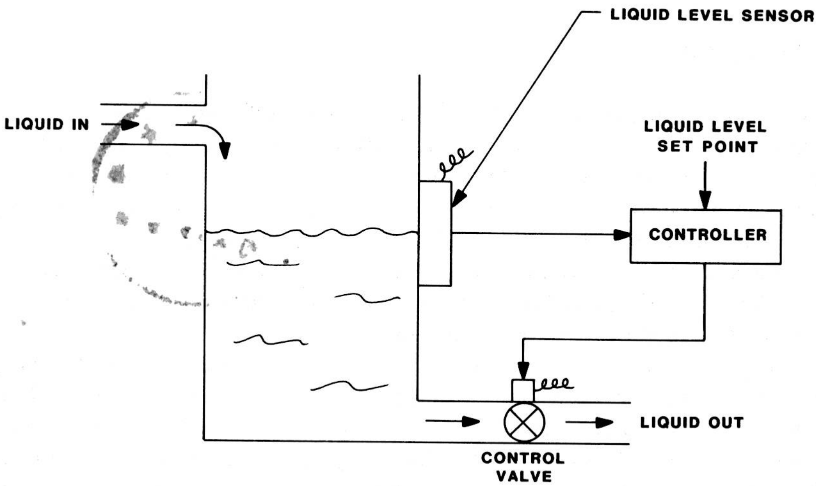

Figure 1–4 SINGLE-VARIABLE PROCESS

Two Single-Variable Processes With Interacting Functions

In this application there are two independent variables, liquid level and *liquid temperature*. Each variable is independent of the other. A complete process loop for the liquid level includes the liquid-level sensor, the control valve, and the controller (see Figure 1–5). The liquid-level sensor senses the level and informs the controller. The controller compares the information to the set point and instructs the control valve to open, thereby lowering the liquid to an acceptable level.

A complete process loop for the temperature includes the *thermocouple*, the controller, and the heater. The thermocouple senses the temperature of the liquid and informs the controller. The controller compares the information to the set point and instructs the heater to heat the liquid to a temperature that is acceptable.

These two independent processes are independent but interactive. As the level of the liquid in the tank changes, new liquid is flowing either into or out of the tank. The change in liquid will invariably cause a change in liquid temperature. Therefore, the action of one process interacts with the second process.

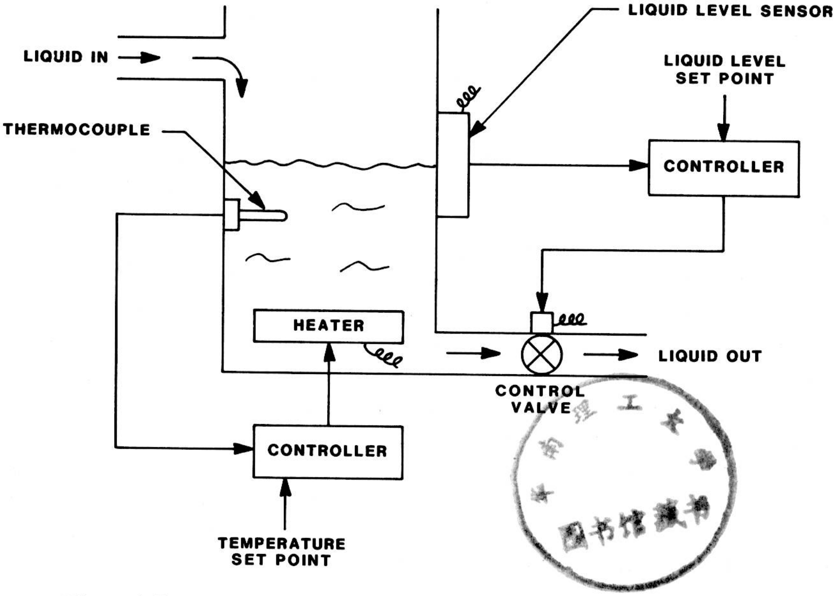

Figure 1–5 TWO SINGLE-VARIABLE PROCESSES WITH INTERACTING FUNCTIONS

Two Dependent Single-Variable Processes

The processes shown in Figure 1–6 have two liquid-level sensors. The input liquid-level sensor senses the liquid level as the measurement device that provides feedback for a flow control valve at the input. The amount of input flow is controlled