Instrumentation Fundamentals for Process Control

INSTRUMENTATION FUNDAMENTALS FOR PROCESS CONTROL

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Preface

This book is conceived as a practical guide and introduction to the principles of process measurement and control to those who are entering, or contemplating a career in the instrumentation and control industry. The work is not intended to supersede the formal mathematical treatment of control theory that is, and will continue to be, an essential requirement for a rounded understanding of the subject. It may also serve as a refresher for those practicing the "art" and who feel the need to look again at the basics.

I have tried in general to avoid the essential "heavy" mathematics normally associated with control theory, because a full treatment of this topic can be obtained from the many excellent publications available. The reason for presenting this less mathematical treatment of the subject is that, in the world of applied instrumentation and control, one often does not need to draw on the formal mathematical approach learned in one's university or college course. The practicing control engineer will, of course, occasionally be called upon to carry out a formal theoretical analysis of an application to determine a solution and on these occasions the academic approach will be found to be valuable, if not a necessity.

For the most part, the topics covered in this book were the subjects of a series of lectures and the chapter contents formed the notes handed out to the attendees. It is for this reason that the language is deliberately intimate and the derivation of most of the various formulas given has been covered in detail. Regarding the level of detail in the mathematics used in the text, I would like to state that it is intentional and has been in response to several requests by those attending the talks for a step-by-step explanation. In this regard I ask the readers' forbearance, as I am sure that some may find the solutions somewhat tedious in their execution.

For newcomers, especially those readers who are currently pursuing a course of study in another discipline, many of the explanations and supporting formulas have intentionally reverted to the subject of physics, where they have their foundation. It is hoped that this method of treating the subject will go some way toward answering the age old question, put by students to many teachers of science subjects in schools, "Where will I ever use this?"

Some of the instruments described in the text may be considered old-fashioned, but this has also been intentional, for these designs show very clearly their dependence on the subject of physics. In defense of the stance taken, I have included modern instruments as well, to try and maintain the balance, for even these newer items of equipment depend on principles established a while ago. It has not been my intention to provide an exhaustive treatment on the topics covered; rather, I have sought to present to the reader the breadth of this most fascinating subject that has given me so much pleasure, and a little pain, in acquiring a level of understanding gained over years in the industry.

It is with much admiration and respect that I mention the part played by so many of my colleagues in the Foxboro Company, now a division of the Invensys Group of companies, and in particular Messrs. F. G. Shinskey, P. Badavas, and M. J. Cooper for their inspiration. I further take this opportunity to acknowledge the stoicism of the several people who attended the series of talks and the many kind words offered, and to thank Mr. G. W. Skates of Honeywell Control Systems and Messrs M. J. Cooper and J. Whiting of Foxboro for their great interest and encouragement throughout the entire series of lectures. I also wish to acknowledge the many helpful suggestions made by Messrs. P. Males of Honeywell and P. Robinson of the University of Plymouth and to thank them for their time in reviewing the initial work. My grateful thanks are also due to Messrs. J. Gough of Foxboro, M. Doyle of CISE (North) Ltd., M. Machacek of Apax Computers, and Mr. D. R. Beeton, a good friend and former colleague at Foxboro, for reviewing the present work; and, last, but not least, my wife Halina for her patience and understanding during the prolonged preparation of this book.

Doug deSá

April 2000

Introduction: Concepts in Instrumentation for Process Control

The power of logical reasoning distinguishes humans from all other species, and it was as a consequence of this capability that they made very significant progress. Their development of tools and techniques for exploiting the materials around them stemmed from their ability to analyze a situation and draw conclusions. Discovery of the means of generating fire at will, and the methods to regulate its intensity on demand, caused radical changes in humans' way of life and thinking. The reaction of materials to fire spurred the need to understand their properties and the rules governing their behavior, in order to derive the most benefit and use from them. The ancient alchemist with his potions, chants, and bubbling cauldrons brought advancement of a kind, but people such as this have long since given way to technical innovators like Galileo, Newton, and many others.

With every scientific advance, the material expectations and demand for newer and better products increased. However, when higher prices were demanded for these enhanced products, the public support did not materialize, even for popular items. It fell to scientists and engineers to develop the technology to meet these demands and to provide an expanded and improved range of products, and at affordable prices.

These goals of product improvement and diversification within financial constraints are just as valid today, as they continue bringing the need to increase scientific research, and to develop new or enhance existing technology. Above all, they demand an increased sophistication in measurement and control technology. With an increasing number of new measurements to be made in combination with a narrowing of product tolerances, those scientists, engineers, and technicians involved in the development of measuring techniques and equipment find their role continually expanding. The measuring instrument, control device, and control systems industries are growing and will continue to do so in line with the other branches of science.

FUNDAMENTALS OF PROCESS CONTROL

This book is devoted to providing a working knowledge of process control and its technology, which many will find intellectually stimulating. One of the first concepts we must get to grips with is, what constitutes a process? In order to provide a reasonable answer, we will have to realize that a process can either be a whole manufacturing sequence consisting of a collection of individual stages or comprise just one stage in that sequence. The simplest definition of a process would be a series of manufacturing stages, which could be either mechanical, electrical, physical, chemical, or a combination of all these, that the feed material or materials would have to undergo to be transformed into the desired end products.

To illustrate what has just been said, let us consider just one stage, and for simplicity we shall not consider it to be a materials processing one. Let the "stage" be the living room of a house in which there is a heater of adequate size, fitted with a switch enabling it to be turned on or off. The room has a door and a window, and the insulation is fairly good; as an added feature, let there be a wall-mounted thermometer fitted. Now let us assume that it is winter and a person enters the room, ensures the door and window are closed, turns the heater on, and settles down in a chair to read. Under the action of the heater, the air surrounding the occupant will start to rise in temperature. The actual temperature attained can be read at any time from the wall mounted thermometer. The air temperature will continue to rise until it reaches a value such that the occupant feels compelled to either turn the heater off or open the window or door to limit the increase. Depending on the size of the heater and whether the window and door remain shut, the temperature in the living room could become intolerable if the occupant took no action. In this scenario, we have all the requisites of a *temperature control loop*:

- A *measuring device*: the occupant and validation using the thermometer
- A *controller*: the occupant
- A *controlled device*: the heater with its switch

If we analyze this example further, we see that:

1. In this particular example, *the measuring device is an intrinsic part of the controller.* This is not the normal case; it is more usual to have the measuring and control functions as separate entities even though they can be physically contained within the same housing.
2. The *heat generated* is transmitted to the air in the room by convection currents, and thus there are bound to be areas that will take a while to warm up, resulting in temperature variations in the room. This will certainly affect the reaction of the occupant.
3. The location of the *temperature indicator* is important in order for the reading to give a meaningful value.
4. The *controller* (the occupant), we shall see, has the following "attributes":
   - A *sensor signal proportional to the measurement*: the occupant's ability to detect a change in temperature and validate it via the thermometer.
   - A *desired value*: the occupant's built-in "comfort" temperature value, called a *setpoint*.
   - A *comparator*: the occupant's ability to compare, i.e., to determine the difference between a desired value and the detected temperature, the difference being called the *error*. If the detected temperature is above the desired temperature, the error is considered positive; and if it is below the desired temperature, the error is considered negative.
   - An *output*: The occupant's action of switching the heater will depend on the following conditions:
     a. If the error is negative, then the occupant will allow the heater switch to stay on.

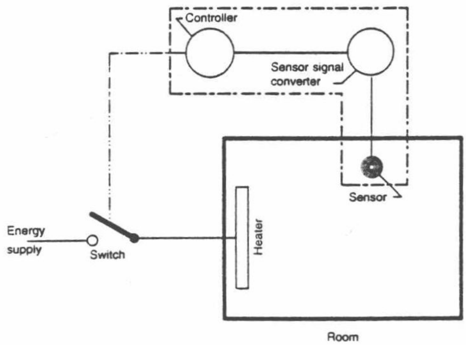

Figure 1: Expanded schematic of control loop.

b. If the error is zero, then there is a "don't care" situation. However, leaving the heater switch on will raise the temperature, or turning the switch off will allow the temperature to fall.

c. If the error is positive, then the occupant will turn the heater switch off.

Note that *the controller always responds with an action that will tend to bring the measurement and desired value to coincidence.*

5. The *control loop* is entirely self-contained. That is, the controller—the occupant—acts on the measured variable, the air temperature within the room, via the heater to provide comfortable conditions. Such a self-contained loop is called a *closed loop*.

Having given a very simple outline of a control loop, let us now depict it in typical graphical symbols, as in Figure 1, but in this instance let us keep the measuring and control devices separate. For the present, we shall maintain the on/off control strategy; we shall discuss alternatives a little further on. Note that in this example the occupant represented in Figure 1 by the box containing the sensor, the signal converter (a means of changing the sensor signal to one that can be recognized by the controller), and the controller are all actually located within the confines of the room itself. The heater switch should also be within the room. This depiction is for clarity only.

As we have seen from our example, we will never obtain a room temperature that coincides exactly with the desired value. On the contrary, we would obtain a room temperature that was on one side or the other of the desired value. This scattering of temperature values will form a band encompassing the desired value over a period of time. The width of the band will, in very simplified terms, depend on the amount of heat, the rate of heat loss, the time it takes the heater to provide the make up amount of heat to restore the lost heat, and the deadband of the sensor and controller. The *deadband* is defined in Figure 2 as the amount of change, in the direction of the measured variable producing it, that occurs during the interval required to produce the appropriate signal. In this respect the deadband is very akin to the inertia of a body or system.

Since the losses are more or less continuous and are being made up only during those periods when the heater is switched on, it will be appreciated that if the actual room temperature was plotted graphically against time, the trace would fluctuate

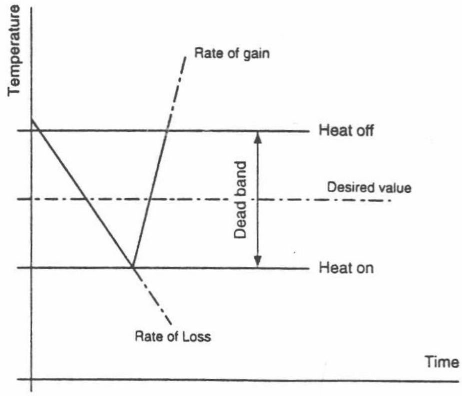

Figure 2: Measurement deadband.

around the desired value. The slope of the part of the curve representing the heat loss might not be identical to the slope of the heat gained part (see Figure 2). The slopes are dependent on the differing rates of heat loss and heat gain; the physical location of the sensor also has a marked effect, because it would not be measuring the temperature of the room, but that in its own vicinity only. In this part of the discussion, remember that the room temperature is a measure of the heat content.

In any control system, process or otherwise, the objective is to achieve coincidence between the measurement and the desired value; anything other than this indicates poor or no control, depending on the amount of separation between the two. Let us now carry the illustration a little further, this time adding instruments to perform the various tasks that humans could do—but not as efficiently—for tiredness and boredom would be the major drawbacks. Before proceeding too far, we should state what we mean by the words *instrument* and *control*, which will be used very often in this text.

For the word *instrument*, we shall generally mean a measuring device. The science behind making the measurement is something we shall be exploring in the first few chapters. These will provide readers with an opportunity to see how the time they devoted to physics, chemistry, and mathematics can be put to use and was not one terrible waste.

A measuring instrument is frequently fitted with a means of directly displaying the measurement made, usually by a pointer moving over a graduated scale; and/or converting the measurement to a corresponding signal, which could be a pneumatic or hydraulic signal or an electric voltage or current that can vary only over a fixed range of values. The latter type of instrument is called a *transmitter*, for this type of instrument is usually employed to transmit the measurement so that it can be read and/or used some distance from the actual point of measurement. In today's world the distance could extend over thousands of kilometers; signals might be beamed to communications satellites, or, conversely, measurements taken by instruments located in space vehicles, manned or unmanned, might need to be read out on earth. In satellite communications, digital signals are used exclusively and are converted to analog variations if and when necessary.

In process control, the main transmitter signals used are pneumatic and/or electric. Pneumatic signals in measurement and control instruments are not as popular now as they once were, although they are still the virtual de facto standard for driving final control devices such as control valves and dampers—if only by virtue of the purchase and installation price of equivalent electronic/electrical equipment alternatives.

The action of a control valve can best be described by an everyday example. The thermostatic valve on a central heating radiator is in reality a self-actuated control valve fitted with a bimetallic temperature sensor that changes shape when exposed to heat—all metals expand when heated, the amount of expansion depending on the coefficient of linear expansion; two different metals are used for stability—and acts on a plunger in the valve body to regulate the flow of the hot water through the radiator. The rotatable dial on these devices allows the user to set the temperature at which the plunger will cut off the hot water flow. In an industrial control valve the plunger is spring-loaded and moved, say, by a piston in a cylinder—the reverse of a bicycle pump—that is driven by a pneumatic signal from a controller to a position dependent on the magnitude of the signal. The position of the plunger determines the amount of fluid that can pass, and thus regulates the flow of hot water through the pipeline and into the radiator. There are methods other than a piston for driving the plunger, and these we shall also discuss in Chapter 16.

A control damper can best be visualized from the following description: a shaped flap that is constrained to move within a large duct so that its movement permits the effective bore of the duct to be varied between fully open and fully closed to the passage of the contained fluid, usually air or gases.

Pneumatic signals are almost universally in the range 3 to 15 lb/in^2, or 0.2 to 1.0 kg/cm^2 or 0.2 to 1.0 bar, the imperial units being more common in the United States and metric in Europe and elsewhere. Electric signals can be either in mA of current or mV of voltage. The ranges associated with electric current signals are almost standardized at 4 to 20 mA, although 0 to 20 mA can sometimes be encountered; when mV voltage signals are used, the most common is 0 to 10 mV. Sometimes microvolt signals are used but these are most often associated with pH, electrical conductivity, or other analytical instruments; microvolt signals are not used for transmitting over a distance. Should this be required then conversion to a milliampere current is needed.

The usefulness of transmitted signals in a process plant is in overcoming losses when the separation distances are large, and they also simplify standardization of the equipment, the control systems, and the communications within and between them. In this respect, milliampere current transmission has the greater advantage over millivolt voltage, as the latter is more susceptible to electrical noise and transmission line losses owing to the resistance of the interconnecting wire. One could argue that the resistance of the transmission line can be reduced, although this can only be achieved by increasing the cross-sectional area of the wire. Increased wire size adds to the costs and to the difficulty in installation due to the greater physical size and weight of the cable.

Every measurement we make must have a minimum and a maximum value; these values could be negative, zero, or positive and are dependent on what is to be measured, or, more correctly, the *parameter* we are measuring. For example, the parameters temperature and pressure could have minimum or maximum values that are either negative, positive, or zero. To be meaningful, it is important that we state the two values (minimum and maximum) in which we are interested—e.g., −30°C minimum and −5°C maximum, or 0°C minimum and 100°C maximum, or −0.1 kg/cm^2 minimum and 2.0 kg/cm^2 maximum. There is a shorthand way of writing this, which is −30 to −5°C, 0 to 100°C, and −0.1 to 2.0 kg/cm^2, respectively, and it is always called the *measurement range*. The minimum value is called the *lower range value (lrv)* and the maximum value the *upper range value* (*urv*). Be aware that there are other measurables that cannot have negative values, for example, the rotational speed of a motor or the speed of a conveyor belt; in this example during normal operation negative values usually have little real meaning; however, there may be occasions where the conveyor drive needs to be reversed slowly under operator control to eliminate a problem. Subtracting the lower range value from the upper range value (urv − lrv) will give the *span* of the measurement. For the examples given, the measurement spans are therefore 25°C, 100°C, and 2.1 kg/cm^2, respectively.

ILLUSTRATION: A SIMPLE CONTROL SYSTEM

We shall try to make our previous example a little more industrially realistic and at the same time retain its simplicity. To do this we shall replace the person in that example with transmitters and controllers having a continuously variable output, which is proportional to the error (i.e., the output will be proportional to the difference between what we measure and what we want the value to be). Every automatic (nonhuman) controller is designed to operate with:

- A desired value that can be set by the process operator or by some other device, which could be another controller, or can be computed by a software routine in a computer. When set by the operator, the desired value—the *setpoint*—is termed the *local* setpoint. When set by another controller or a computer, it is termed the *remote* setpoint, sometimes also called the *cascade* setpoint.
- An output that results from computations (analog or digital) within the confines of the controller itself is deemed to be *automatic*; alternatively, the process operator can drive the output *manually* to a value judged to be necessary. These ways of producing the output are called the operating *modes* of the controller. The modes are selectable by the operator and can only be invoked one at a time. Changing the controller mode from Auto to Manual has the effect of "freezing" the last value of the output, or allowing it to be adjusted by the operator; while reverting to Auto unlocks the output, which will change to a computed value based on the error.

COMPONENTS OF THE SYSTEM

In the example that follows, some liberties have been taken in the interest of simplification to show how the process works. It is possible in the food industry for juices, syrups, and milk to be thickened in specialized vessels called evaporators, of which there are different types, such as the *falling film* used in the concentration of milk or glucose. In practice there is usually more than one vessel involved, each vessel being called an *effect*, the process of concentrating the raw product being spread over several effects. This collection of effects is called a *multiple-effect evaporator*, the actual number of vessels used depending on the material being processed.

Let us assume that the instrumentation is analog and a cylindrical vessel, as shown in Figure 3 that has a heating jacket partially covering its lower portion, replaces the room in the previous example. The jacket forms what can best be described as a second skin. The vessel forms one part of a system used for reducing—by evaporation—water-rich, fresh, edible juice to a thicker fluid called *concentrate*. To retain the taste, the evaporation of the excess water is carried out at a pressure that is lower than the ambient so that the temperatures involved are not high enough to cook the fruit. Heat is imparted to the process fluid (juice) by steam, in a way that allows the juice maximum exposure to the heat source. Hence, steam enters through a connection on the top part of the outer jacket, and exits as hot water—when steam

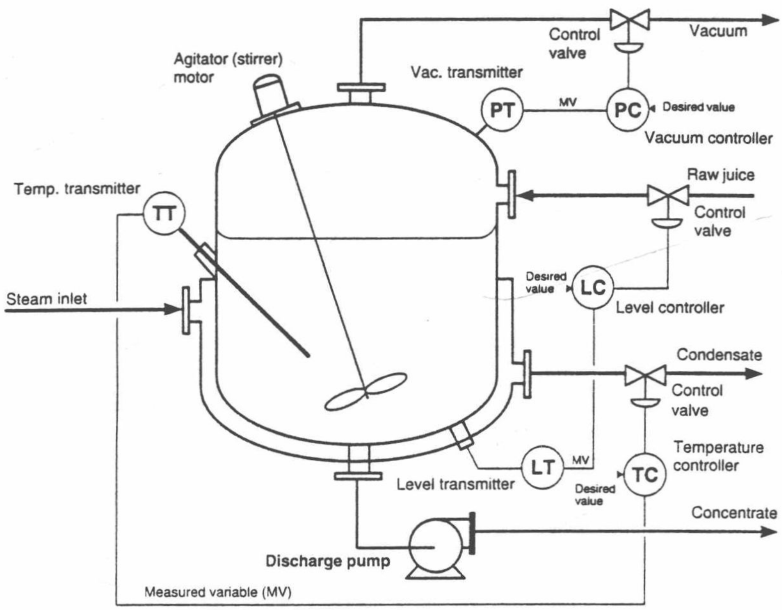

Figure 3: Simplified edible juice concentrating control scheme.

gives up its heat it will condense back to water, in which state it is called *condensate*—from a connection at the lower part of the jacket cavity. Such an arrangement in a real process vessel is called a *steam heating jacket*, but there are other methods of steam heating that involve introducing the steam either through a *steam heating coil* fitted within the vessel, or directly into the liquid, when the technique is called *live steam injection*. Both of these latter methods are unsuitable for this particular application. If used here, steam heating coils can become clogged with the concentrate, permitting bacterial growth, which is a health hazard; or live steam injection will dilute the juice and therefore be counterproductive.

The vessel is fitted with the following:

- A level transmitter and its associated control device, which acts through a control valve in the supply line delivering the raw juice.
- A temperature transmitter and its control device, which acts through a control valve in the condensate line and not in the steam line, as some might have expected, for economic and heat conservation reasons.
- A vacuum transmitter and its control device, which acts through a control valve in the vacuum line.

The three control valves are used to regulate material flow through the pipelines. The whole arrangement is shown in Figure 3.

In Figure 3, each function has been shown separately, as is normal for this type of diagram. For convenience, the measurement (i.e., MV, or measured variable) and the desired value for each controller have been labeled. As we stated earlier, the measuring and control devices are analog instruments; hence, the monitoring and the control functions will be continuous—i.e., their signals will trace smooth curves with respect to time. Now if the control valves are also continuously variable, then they will respond to the variations of the controller output and as a result will, in time, change the measurement. A suitable analogy of what is happening here would be the accelerator pedal and speedometer on an automobile. The driver varies the travel of the pedal continuously to suit the road conditions and also to stay within the speed limit. However, from experience we know that there is always a delay between a change in pedal position and the change in speed of the vehicle. In control parlance, this is an *output lag*.

OPERATION AND REGULATION

The sequence of actions we shall describe next typifies the actions of a process operative in control of a single evaporator in the middle of a multiple-effect evaporator processing system. The process operator vents the vessel, sets the required vessel level as the setpoint on the level controller, and sets the mode to Auto. This allows the control valve in the raw juice line to open and start to fill the still vented vessel. The controller monitors the level, regulates the juice flow, and, when the measurement coincides with the setpoint, closes the vent and supply control valves. With this system, the operator will have to change the mode of the juice controller to Manual to keep the control valve shut to allow the contained juice to be concentrated.

The stirrer motor is switched on at a predetermined juice level to avoid stratification; because juice is a solution of salts, solids, and water, separation will occur naturally in time. The other important and very beneficial effect of stirring (agitating) the juice is to ensure a uniform temperature through its whole mass.

The process operator then sets the required juice temperature on the temperature controller—as mentioned earlier this has to be much lower than the boiling point of the juice at atmospheric (ambient) pressure to preserve the taste—and sets the controller mode to Auto to allow it to admit and regulate the heating steam to the jacket by allowing some condensate to leave the jacket. When the juice temperature reaches the setpoint, the controller closes the condensate valve fully. The process operator leaves the temperature controller mode in Auto to maintain the temperature in the vessel. Note that what has just been described is deliberately very simplified, since what is required is the admission of some heat (steam) to replace that which is lost due to evaporation and the surroundings.

While the juice is attaining the required temperature, the process operator sets the vacuum required by gently raising the value on the vacuum controller (for reasons given later in this section). Be aware that a lower pressure will increase the observed liquid level, and if the level controller had been left on Auto, this would drive the valve open and upset the required thickening process. At this point the vacuum controller is still in the Manual mode from the previous operation, which holds the vacuum valve shut. When the desired temperature throughout the mass has been reached, the process operator changes the vacuum controller mode to Auto, which will drive the vacuum control valve open thereby reducing the pressure in the vessel. The juice starts to boil, but at a much lower temperature than would be the case at ambient pressure, and forcing some of the water in the juice to change to steam which is either vented or removed up the vacuum line for further use.

Since the juice is giving up part of its water content, it will become more dense (undergo a density change) and thicker (more viscous), and the level in the vessel will fall commensurably. The object in most liquid food concentrating processes is to reduce the inlet volume to about one-third the initial value. The process operator monitors the level in the vessel and changes the vacuum controller mode to Manual when either the desired level or concentration is attained. There is normally a vent line on the vessel (for simplicity, this has been omitted on the drawing), which is slowly opened by the process operator to allow the vessel to attain ambient pressure. When ambient pressure is reached, the discharge pump is started to empty the vessel to make it ready for the next "charge" of juic; this is typically a *batch process*.

Two important points have been smoothed over in the preceding description, and these should be explained before we progress too far. First, it is very important that a controller mode be changed from Manual back to Auto only when setpoint and measurement are aligned, for this will avoid a *bump*—a rapid change in the measured condition—in the process when the control valve has to react suddenly to a change from its initial position to that demanded by the controller. The severity of the bump will depend on how far apart the setpoint and measurement are at the time of transfer. Modern controllers are designed to balance the measurement and the setpoint automatically by what is called *bumpless Auto/Manual transfer*. The second point is that the opening of the vacuum control valve should be gentle. It should not be too difficult to imagine the drastic effect that a sudden exposure of a pressurized vessel to a vacuum could have on the process fluid; it will tend to all froth up and rush out immediately. To avoid this, the setpoint on the vacuum controller should be slowly increased to the desired value, or, in other words, there should be a *ramped setpoint*, the idea being to have the measurement and setpoint change in unison.

This extremely simplified semiautomatic control scheme on a single evaporator vessel will show that instrumentation and control allow an ever vigilant check on the more mundane parts of the process with minimal operator intervention. Consistently repeatable product quality will inevitably follow, provided that the operator makes the changes of controller mode at the appropriate times.

MODERN INSTRUMENTATION AND ITS EVOLUTION

Even from this brief illustration it should not be too difficult to visualize the possibility of a more fully automated process, still manipulated by means of small individual control loops, but using the refinements of modern control equipment. However, this is not the end of the control story, it is only the beginning. To obtain a much more appealing product, the temperature rise initially imparted to the raw juice should not be detrimental to those enzymes and volatile components that stimulate the taste buds, and this will involve processing the juice in more than one vessel, for we can then preserve the quality needed by not adding heat, but reducing the boiling point temperature in small stages as a result of progressively increasing the vacuum in each succeeding process vessel. In terms of energy saving, there is every reason to utilize the steam extracted in the first evaporator vessel as the heat source for succeeding evaporator vessel(s), or even to warm up the incoming raw juice. There is a limit, which lies in the efficiency and running cost of the vacuum system, that dictates how far this can be carried through. The hot condensate can also be used to, say, wash the raw produce from which the juice was obtained.

Our experience of the real world tells us it is highly unlikely that there is such a thing as a single independent process parameter; most are to some extent interactive. In some cases, because of the complexities of taking *all* the interactions into account for very minimal actual results, we employ simpler but effective control schemes that have a consistent and desired effect. Herein lies the fascination and the challenges of the science and technology of control and instrumentation.

Manufacturing processes are becoming ever more complex. For instance, we no longer distill crude petroleum for just providing automobile gasoline, a few aromatics, kerosene, some lubricating oils, wax, and tar. Now the products derived from the same raw material, crude petroleum, have been diversified to such an extent that there are, to mention a few only, several grades of gasoline to cover aviation and automobile requirements, jet fuel, heating oils, a whole range of products that form the basis of the petrochemical industry, dyestuffs, a lubricating and cutting oil industry, a range of waxes, bitumen, and some pharmaceuticals. The same story is repeated in the pulp and paper, food and drugs, water and sewage treatment, and gas and power generation industries. To achieve this kind of development, chemists, physicists, and chemical, mechanical, and electrical engineers have been fully and ably supported by instrument and control engineers, for it is due to these latter technologists that we are able to obtain in quantity and quality the whole range of products that we take for granted.

To focus the discussion, it is difficult to envisage a business environment of the future, whether it be short or long term, that will be successful when using the methods and technology of the past. Concern, in any manufactured product industry at the present and for the foreseeable future, is with the multiple requirements of producing the goods for the:

- Minimum manufacturing cost
- Maximum return on financial investment
- Minimum consumption of nonrenewable raw material resources
- Minimum demand on energy and maximum use of that consumed
- Greatest possibility for recycling at the end of product life
- Minimum waste

To achieve all of these is a task that will demand much ingenuity and skill of all the personnel involved. In any case, how well the objectives are met will involve good, careful design and close monitoring at every stage during the manufacture of the product. Out of overall process plant capital costs, instrumentation and control systems account for approximately 3 to 9% for *continuous processes* and up to 15% for *batch processes*. A *continuous* process is one that takes a constant stream of raw material, performs some work on it, and obtains the final product(s) at the output of the process. A *batch* process is one that is very complex and takes in specific quantities of several raw or processed materials or combinations of both at very specific points in the manufacturing cycle to obtain a (comparatively small) quantity of product that is usually technically sophisticated and expensive; pharmaceutical products are an example. It is not a shortened version of a continuous process.

These financial investments are a necessary and vital part of the strategy to attain the aforementioned economic goals. Instruments provide a "window" through which the manufacturing process can be observed, both by those who operate it and by the control systems that provide the means of manipulating it. The early individual, large, totally analog indicating and control instruments were at one time the only such equipment available. These instruments had to be accessible to those operating the process and therefore had to be mounted on a plate, which became what was called an "easel-type" panel. As process complexity grew, there were a greater number of measurements to be made, and therefore many more instruments that had to be mounted; necessary steps were taken to reduce instrument size and format but without sacrificing readability. The easel panel gave way to the "cubicle" and "control console" types of panels, for reasons of stability and compactness, scheme complexity, and numbers of indicators, controllers, lamps, and switches involved. In spite of the reduced physical size of the instruments, control panels could in some instances have a length of tens of meters. To assist the operator and reduce the mental burden, fixed pictorial representations of the process, or *mimic diagrams* were added to the panel. These pictures would be, say, of a process vessel with the main material feed and process pipelines, each painted in a different color for easy recognition of their function and the material flowing in them. In some instances the actual associated instruments were mounted in the correct relative position in the lines to provide a vivid visual display. Once again, process complexity and sheer number of measurements forced large-scale pictures of the vessels to be abandoned and replaced with symbolized versions containing lamps of different colors that illuminated to depict the "health" or status of each pipeline or vessel. The associated instruments were located on the panel, but away from the picture. From this developed the highly symbolized and stylized pictures of the process and what are today called the *process graphics*.

The physical size of the control panels meant that the control rooms within which they were located also had to be large. Coupled to this was the fact that each item in a control loop had to be individually piped or wired. If computations were involved, then the number of components in the loop increased, and correct scaling of the signals was vitally important for correct results from the signal manipulation. Corrections or modifications to the control room and the control loop were an expensive affair in terms of both money and time. These difficulties were the incentive to search for a solution, which eventually resulted in large pneumatic-driven systems becoming less prevalent, and the application of the semiconductor and the emerging integrated circuit to increasingly provide the answers. The transistor and its developments brought very rapid transition in their wake from analog-to-digital techniques, which in turn gave the world *microprocessor-based individual controllers* and the *distributed control system* (*DCS*). New microprocessor-based individual controllers have very largely superseded the old style "moving pointer" display instruments. These new devices are hybrid, in that they still use analog input and output signals that are usually in the milliampere current range (4 to 20 mA) but internally carry out the functions digitally much like the pocket digital calculator. There are no moving parts, and the instruments are fully programmable and provided with facilities enabling them to be interrogated and commanded by a digital computer if required.

DCS systems are discussed further on in this book. Briefly, in these control systems the process measurements and the controlled outputs are physically separated from the control and computation functions, but all are interconnected as required by cabling and software links. The control, computation, and logic capabilities are held as *algorithms*—predefined sequences of software routines for calculation and/or logic—that can be invoked by the control system designer on demand to perform specific control, computation, or logical functions. The system includes a *keyboard* (a standard computer keyboard) for giving instructions to the system; a *printer* for outputs and messages from the system; and a *visual display unit* (*VDU*) or monitor, through which the process operator is able to view and manipulate the whole process, usually only one section at a time, via the keyboard and/or a mouse or trackball. The process engineers can additionally change parameters, measurement ranges, and *alarm points*, i.e., points in the measurement range where the process parameter is considered to be approaching a hazard. The foregoing process data accessible to the process engineer is *protected* in that only authorized personnel are allowed to make changes to it to provide security of the formulation and ensure consistent product quality. The DCS arrangement allows very large control panels to be dispensed with; and since all internal interconnections are made by software and not by physical wiring, it enables modifications and rearrangement to be implemented relatively quickly and without undue difficulty.

It is a fact that the lifeblood of all modern control systems is data and information manipulation; this aspect has been given a great deal of prominence in recent times, but why should it be? Data and information are nothing new; it has always been there and available. The truth is that only now is the enabling technology and expertise at our disposal to begin to exploit the vast amounts of information being continually generated. It is possible to propose a scenario where allocation of the size (quantity) of production runs, which is normally based on process management personnel's best guess of sales and marketing demand, can be dynamically modified by the management supervisory computer system to reflect values based on the actual volume of product sales. More *intelligent measuring and transmitting instruments*, some of these new instruments already with us and in use, provide measurements to limits hitherto impossible, are capable of being reranged remotely through a keyboard or a handheld configurator, and can include measurement data validation and many more features.

As a direct consequence, the whole business operation—administration, procurement, manufacturing, sales, and product development—will be made to run at a level most advantageous to the improvement of cash flow and profitability of the corporation, and will become more adept at conserving our nonrenewable natural resources. The bedrock of such an enterprise is professionally qualified personnel with a high level of business acumen and technical ability in management, manufacturing, and product development. Assisting these persons in their decision making will be very powerful, easily configurable computer control systems providing up-to-the-minute reporting on throughput, quantity, and quality of both raw and finished materials. The combination of vision and fact set out in the scenario is gradually taking shape; it will be the way forward. Without capable and innovative instrument and control engineers, however, the chances of achieving this scenario are slim. It is hoped that this book will be a start for the reader to a fulfilling and exciting future.

SUMMARY

1. A process can be defined as a series of manufacturing stages, which could be either mechanical, electrical, physical, or chemical, or a combination of all these, that the feed materials would have to undergo to be transformed into desired products.

2. Flow, pressure, level, temperature, and similar quantities are called *parameters* of the process variable.

3. A control loop in general comprises a measuring device, a controller having the desired value (setpoint) that can be set by the process operator, and a controlled device. However, when the setpoint of one controller is set by another controller or a computer it is termed the *remote* setpoint, sometimes also called the *cascade* setpoint; such a combination is called a *cascade loop*.

4. The separation between the minimum and maximum values of a measurement is called the range, and the difference between lower and upper range values is the measurement span.

5. A controller must include all the following components: a measuring unit, a setpoint, and a comparator to determine the difference between setpoint and measurement to generate the error; a control unit that operates on the error and