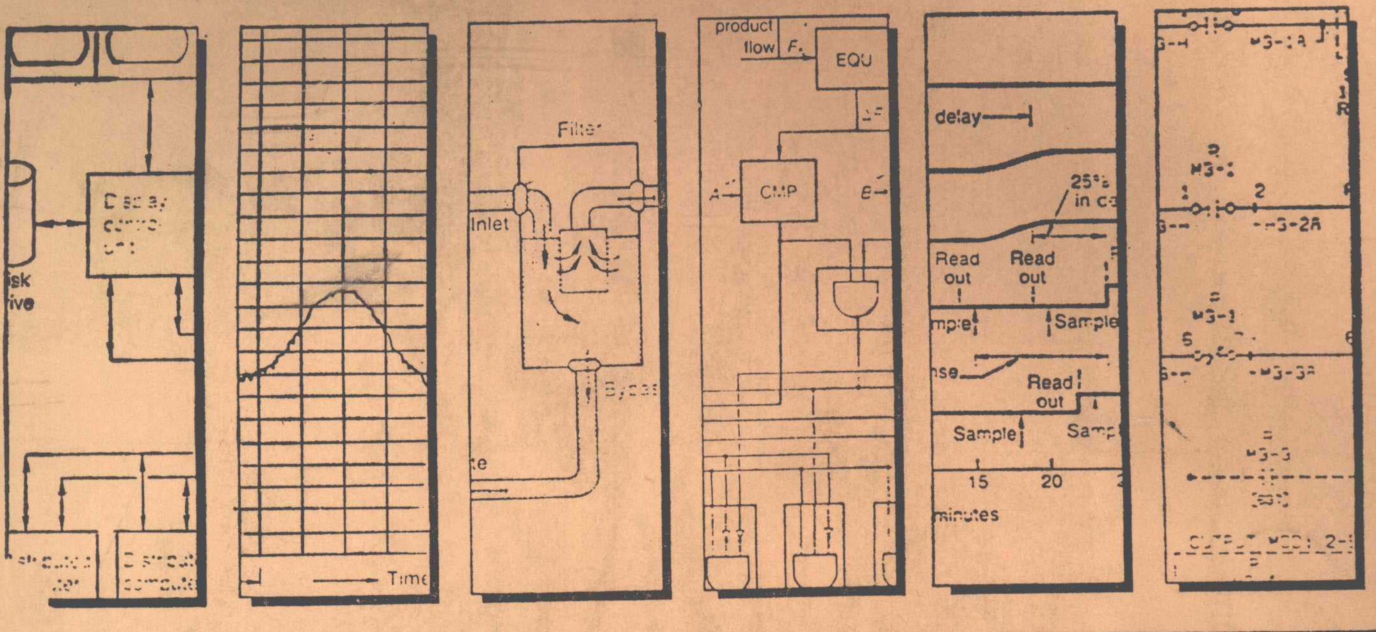
Handbook of
Advanced Process Control Systems and Instrumentation



Les Kane, Editor

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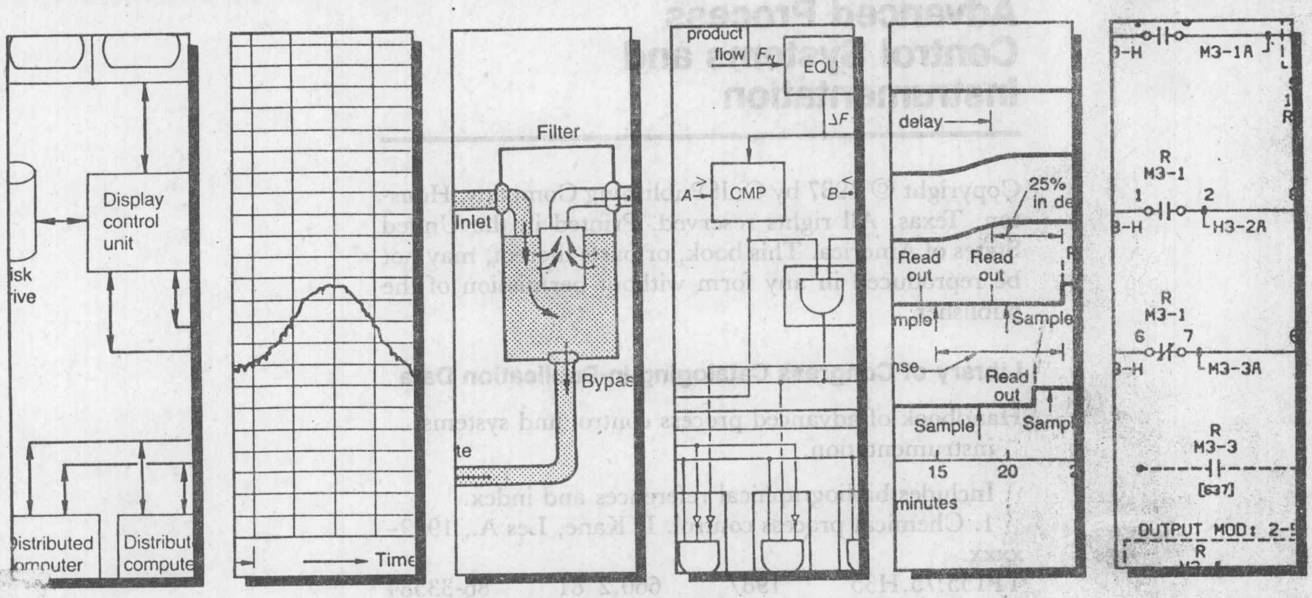

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Library of Congress Cataloging-in-Publication Data

Handbook of advanced process control and systems instrumentation.

Includes bibliographical references and index.
1. Chemical process control. I. Kane, Les A., 1949-
xxxx.
TP155.75.H35 1987 660.2'81 86-33584

ISBN 0-87201-721-4

Handbook of

Advanced Process Control Systems and Instrumentation

Gulf Publishing Company
Book Division
Houston, London, Paris, Tokyo

Preface

This book is designed to provide process control engineers, instrumentation engineers, process engineers, and management a practical guide to improving process control. The information presented is unusual for books of this type because it reflects practices used in the real world. Unlike textbooks, this book integrates problems, concerns, and actual experiences in implementing better control and relates them to the control technology.

Since processing plants vary considerably in their level of control, the book includes basic information for those just getting started, and progresses to include some of the most useful information available on the latest practical advanced control techniques. The chapters are adaptations of articles published in *Hydrocarbon Processing* magazine and reflect the progression of process control in the 1980s. They also adhere to the magazine's editorial philosophy of presenting the users' viewpoints rather than those of the manufacturers.

One important conclusion reached in review of the book is that a thorough understanding of the process to be controlled is critical to maximizing the benefits of modern control systems. Hence, considerable information is presented on specific process control strategies, process conditions, how process variables affect profitability of specific processes, etc.

I welcome any comments on the book and hope you find it useful.

Les Kane
Engineering Editor
Hydrocarbon Processing

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Control System Design: A Brief History

B. D. Stanton

Over the past forty years the measurement and control business has changed significantly with regard to plant operation methods, plant complexity, and types of control equipment and measuring devices. Some basic things that have not changed are the need for good fundamental control systems engineering, basic single-loop control systems, and maintenance requirements. This chapter discusses the evolution of the process control system, some of the present problems we are facing with suggested solutions, and finally a look to the future.

INCENTIVES FOR NEW INSTRUMENTATION

The basic driving force of any industrial venture is the increase of profit. Profit is a function of yield of valuable products minus the cost of producing them. The effect of this interrelationship upon the process measurement and control industry can be seen by looking at examples of cost reduction and yield improvement.

Very high fuel costs have brought process heaters under close scrutiny with regard to design and measurement of efficiency. Measurements of oxygen, carbon monoxide, carbon dioxide, fuel Btu, and accurate flow are used to calculate efficiency. These measurements are of great value to plant operation, but they are even more valuable if inputted to a computer where efficiency calculations are made, safety constraints checked, and feedback signals sent to front-line controllers to bring the process to the optimum operating position. This type of operation decreases cost and thus increases profit. However, capital equipment expenditures, design engineering, software, and maintenance costs are higher.

In the area of increasing yield for greater profit, a classical example can be seen in the distillation tower. Here, computers that use on-line analyzers (themselves computer controlled) and flow meters (which are computer compensated) adjust the column to give the maximum amount of the more profitable product.

The basic requirements of computer control systems are:

- Good systems design
- Good basic measurement
- Use of computational devices to optimize the system
- Good maintenance after the system is operational

The last four decades have seen significant improvements in measurement and computational equipment. Basic measurement standards have been developed based on experience and theory. A large variety of on-line analyzers are available that do work when properly installed. On-line computational equipment that works is commercially available.

If this is true, then where do our problems exist? Problems are found in basic system design and maintenance. This chapter will present several illustrations of these problems. But first, let us look for a moment at measurement and control history; this will help us understand how we got where we are today. The following discussion is illustrated in Fig. 1 and tabulated in Table 1.

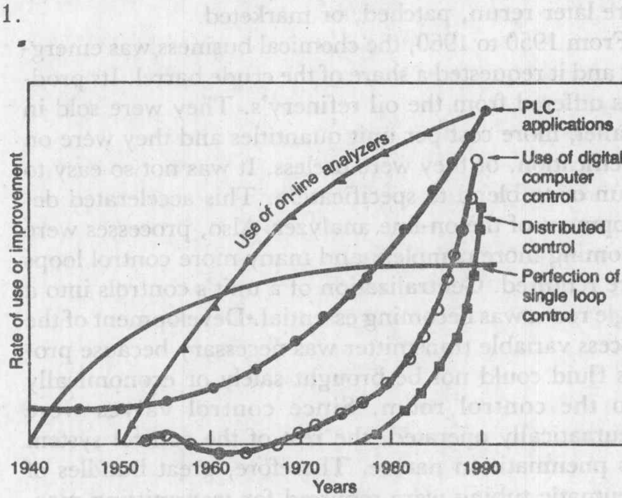

Figure 1. Trends in instrumentation.

Table 1
Control System Development

1940 - 1950	Development of single loop P.I.D. control. Start of unit control rooms.
1950 - 1960	Transmitters and transmission lines. On-line analyzers. Electronic control loops.
1960 - 1970	Control room consolidation. Digital computer control. Programable logic controllers. High density single loop controls.
1970 - 1980	Central control room, electronic instrumentation. Improved power supply systems. CRT operation distributed control. Microprocessor driven measurement devices.
1980 - 1990	Expansion of digital computer control. Intercoupling complex digital devices. More reliance on complex measurement.

PAST PRACTICES

From 1940 to 1950, operating managers were not in favor of the unit control room and they certainly did not want an air-conditioned room for the operators to work in. Instruments were scattered around in the units, and operators had to walk around looking at their process equipment and instruments. Process fluids were piped directly to the instruments. Therefore, process variable transmitters had not been developed. Single loop pressure, temperature, flow and level control loops were coming into use because the operator could not cover all the bases at once. The processes were simple, and the operator had only 10 to 20 control loops to watch over. Circular charts from flow meters were collected and sent to yield clerks, along with tank gaugings, to make up the unit materials balance reports. Operators kept rather complex hourly logs of operations. Samples were sent to a central laboratory for product composition analysis. All products went to tanks from which they were later rerun, patched, or marketed.

From 1950 to 1960, the chemical business was emerging and it requested a share of the crude barrel. Its products differed from the oil refinery's. They were sold in smaller, more cost per unit quantities and they were on specification, or they were useless. It was not so easy to rerun or to blend to specification. This accelerated development of the on-line analyzer. Also, processes were becoming more complex, and many more control loops were required. Centralization of a unit's controls into a single room was becoming essential. Development of the process variable transmitter was necessary because process fluid could not be brought safely or economically into the control room. Since control valves were pneumatically operated, the rest of the control system was pneumatic in nature. Therefore, great bundles of pneumatic tubing were required for transmitting measured signals. These massive transmission lines were the first cause of the move to electronic-type control equipment. Analyzers normally had to be made using electronic elements and had to be housed in very clumsy explosion-proof boxes.

Vacuum tubes were required in all these electronic devices, and these tubes were problematic. Great discussions were carried on in technical society meetings about the merits of pneumatic versus electronic control. Many lessons were yet to be learned about electronic devices, such as: silver migrates across insulators, shorting contacts, power supplies were not as reliable as desired, the failure rate in electronics far exceeded that of pneumatics, and maintenance men did not have good test equipment nor did they understand how to troubleshoot electronics.

In the 1960 to 1970 period, the digital computer for process control became available causing an immediate revolution in the process control business. There were many problems to be solved, and during these first few years the digital computer barely made, and in many cases lost, ground after attempts were made to apply it.

During this period conventional instruments were being miniaturized and operators were supervising larger numbers of control loops. Alarms became more important because the operator was not able to watch closely all the loops and needed aids to attract his attention to problem areas. On-line analyzers were becoming reliable and were being used as operating guides. These devices needed special installation design and maintenance. The digital computer was hungry for data to solve the problems it could resolve, and the number of back-up devices increased. Programmable-logic controllers (PLC's), which were solid state, were replacing the old relay logic systems. Control room consolidation and management information systems using digital computers were beginning to be seen in plants.

During 1970 to 1980, all of the items of the previous period were refined and used. The swing to total electronic control became strong. Microprocessor-based distributed control came into being. Control room consolidation, and in grass roots plants one central control room, became common engineering practices. Digital computers were starting to do on-line control. Operators were running plants using colored cathode ray tubes (CRT's) as their interface to the plant. Since the control room was located a long distance from the processes and the operator was confined to his CRT's, a radio link to a yard man was essential. The microprocessor began appearing in all types of instrumentation. Data links between computational devices were required. These digital devices had many types of programming languages, and communication links had all types of protocols and error-checking routines. Mixing of different manufacturers' equipment was difficult, if not impossible. Electrical power supplies became critical.

PRESENT CONTROL SYSTEM DESIGN

In our present decade of 1980 to 1990s we have arrived at process control system design as illustrated in Fig. 2. This system can be, and normally is, supplied by eight different hardware vendors. There are normally four to five different programming languages employed and as many as four different data transmission line protocols. The operator's CRT station can have up to five different CRT's. All of these devices are electrical in nature, therefore, they must continue to run no matter what happens to the main power busses. Some of the problems associated with computer control are: ground loops and isolation from stray pulses getting into digital devices; the large amount of stray electrical signals passing through the air; and, finally, most of this equipment must run in a clean relatively stable atmosphere. This puts the air-conditioning system in the reliability loop.

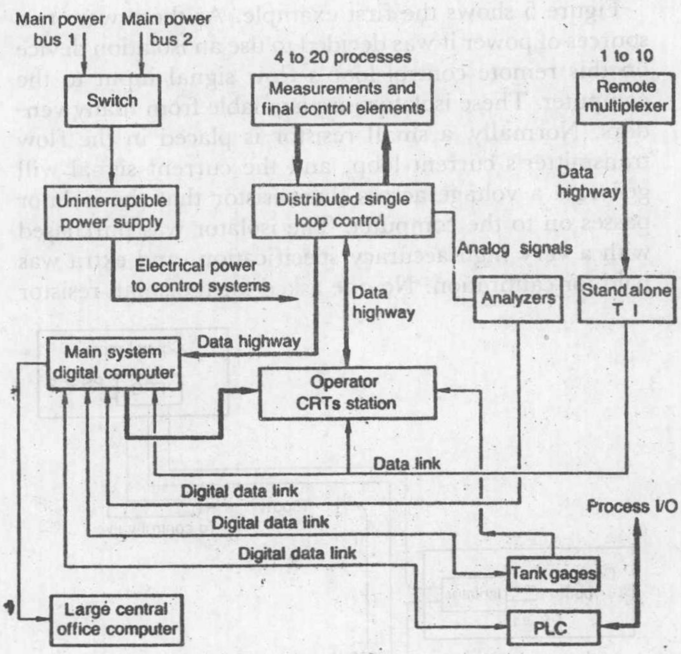

Figure 2. Present process control system design.

We can illustrate this system by making up a hypothetical system using real equipment suppliers. This will highlight the problem of complexity. Table 2 shows such a system. As examples, let us take two of the elements and run across Table 2, Number 3 - "Tank Gauges" and Number 1 - "Stand alone TI (Temperature Indicator)."

Table 2
Hypothetical Control System

Device	Typical manufacturer	Inputs	Outputs	Software
1) Stand alone TI	Transmation	Thermocouples and RTDs to five RTU's	Operator CRT. RS 232 link to computer.	Fixed by manufacturer. Configured by user.
2) Analyzer	Amscor	Hydrocarbon samples	Special data link to main computer. CRT for operator.	Fixed by Manufacturer. Configured by user.
3) Tank gauges	Varec	Level transmitter	Gray code to operator indicator and to digital computer.	None
4) PLC	Modicon	Contact closures	Contact closures. Mod bus data highway to computer & operatof CRT.	Programmed by special ladder diagram technique.
5) Distributed control	Honeywell	All process measurement	Data highway to CRT to operator. Analog signals to plant.	Fixed by manufacturer. Configured by user.
6) Main digital	Modcomp	From all devices using a number of interfacing black boxes	Operator CRT Analog signals to distributed control, typers etc. Link to central computer.	Fortran
7) Measurement and final control elements	Rosemont Fisher control	Process variables 4-20 mA electrical	4-20 mA signal. Manipulation of process fluids.	None

Since the control room is centrally located and remote from the process, tank gauging from the central control room is essential. The tank status must be available to the operator to prevent overfilling or running the tank dry. Also, the computer must have these data for inventory reports. The level transmitter is electromechanical and uses a shaft encoder to convert the electrical signal to a series of pulses. These pulses go out on the line using a Gray code protocol. This code is converted to a decimal display for the operator at his station. The signal also must go to the computer and be converted to a binary format for the digital computer. Note that three different manufacturers of hardware are involved. Either the computer or the operator can request tank gauge data by going back over these data links.

Next, consider the "Stand alone TI," which we have always had to support our process control systems. The cost of running rare-metal thermocouple wire from remote units to the central control room is prohibitive. Therefore, remote multiplexers are located in the units near the measurement points. The central device, which is normally a small digital computer, handles operator or computer requests for data via a data link, by calling up the correct point in the desired remote multiplexer, checking the signal for validity, checking alarm limits, and then sending the data in engineering units to the operator via a digital display or CRT, and to the main computer in binary format via an RS 232 link. This story repeats for all devices. Therefore, the design engineer must be sure all the devices work and do the required job, and that the proper interfaces are supplied between different manufacturers' devices.

Now, how does all this complex system get put together? Figure 3 shows the type of user and user-purchased skills required. The users' manager must be sure that nothing in the interfaces is lost or forgotten. The technical experts usually define what they want and then the contractor executes their desires. There can be as many as five different contractors involved. The contractors must be checked in all phases of their work for accuracy and to verify that the user is getting what he wants. Blood, sweat and tears are usually involved in this detail design phase of the work. After this, the system check-out and field installations must be monitored carefully to make sure nothing is done to impair the operation of these complex systems. Again, although contractors have the job, the user must carefully check the work.

Now the operation and maintenance starts. Figure 4 shows the elements required. There must be a training period to teach operators to use this complex equipment. Often this is done under contract by the equipment vendors. The technicians must go through training similar to the operators' training, and also training on front-line maintenance and trouble shooting diagnostics of both hardware and software. Detailed maintenance experts on all these systems have to be supplied by the vendors. The user's technician can make front-end systems checks and sometimes repair the trouble,

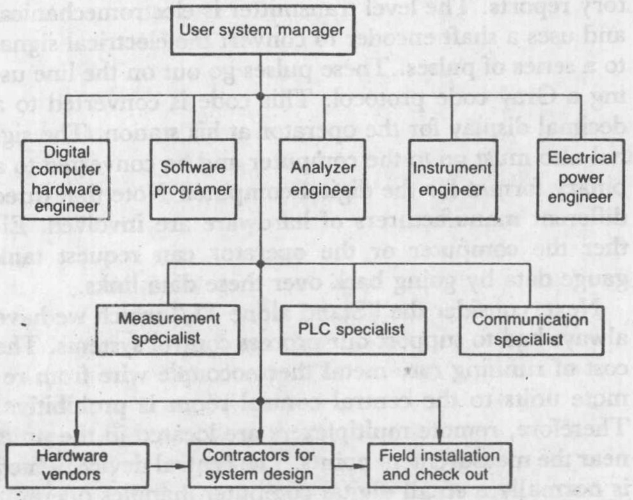

Figure 3. User and user-purchased skills required.

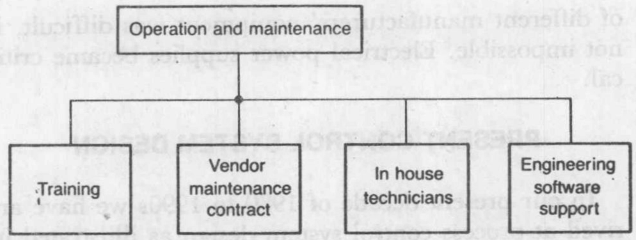

Figure 4. Required operation and maintenance elements.

but if this is not possible he must call out the vendor's expert. After operation starts, the operating department usually finds many things they don't like about the system, or changes or additions they wish to have. This requires knowledgeable in-house engineers to redesign the modifications to the system.

Examples

Now let us relate a few simple practical examples from experience that will illustrate how these complex systems can fool the designer.

Figure 5 shows the first example. As there were two sources of power it was decided to use an isolation device on this remote control loop's flow signal input to the computer. These isolators are available from many vendors. Normally, a small resistor is placed in the flow transmitter's current loop, and the current signal will generate a voltage across this resistor that the isolator passes on to the computer. The isolator was purchased with a very high accuracy specification, and extra was paid for calibration. No one asked for the small resistor

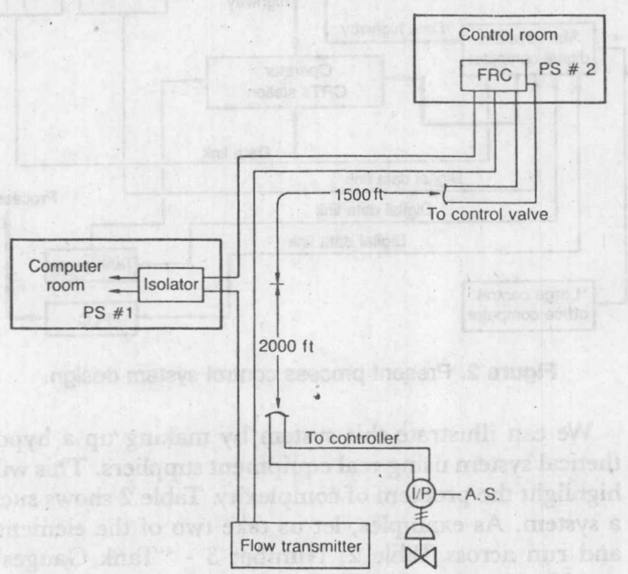

Figure 5. Isolator example.

to be placed on the plug that held the isolator. It was on the printed circuit card. The first time the technician in the computer room pulled this card to check its calibration, the current loop was broken, causing an upset to the flow control loop. The manufacturer would not guarantee the accuracy if the resistor was lifted from the card and placed on the plug. Card removal for calibration checks became very complex. The isolation cards had to be locked in their rack to prevent accidental removal. There were 40 of them in this system. Now the calibration required three sets of technicians with radios at the three equipment locations. One flow meter calibration required six men for one-half day.

Another example has to do with card replacement maintenance. A card went out on a CRT display. The mechanic replaced this with his spare and it immediately failed. Since the spare was not kept hot (on-line), the mechanic assumed it failed on startup and replaced it with his last spare, which also failed. With no spares and no way to tell what the problem was, he called in the local service man. The service man, knowing the circuits on the card, located the failure as 110 volt AC on the input, tracked it down and removed this problem and used his only spare. Now three new spare cards had to be rush-ordered at a cost of $5,000, a service charge was paid, and almost eight hours of CRT display time was lost.

A final example (these could go on forever) concerns a tank gauging system. The computer programmer put the tank gauges on a regular two-minute scan. He had no idea how these devices work and could see no reason for not putting them on a regular scan. Within a few months these electromechanical measuring heads started failing at an alarming rate. When the instrument technician located the problem he asked the computer people to put the tank gauges on an eight-hour scan rate or on demand from the operator. When the operating manager saw this, he was concerned that a tank could be overfilled between scan times. Therefore, a completely separate low-accuracy analog level measurement system had to be installed. These were on a high-speed scan with high/low alarms. There were 28 of these tanks. The low access rate but higher accuracy gauges were also retained, doubling computer tank level inputs.

In addition to many new problems that can be designed into these complex systems, there are all the old standard instrument installation, measurement point location and single loop control problems that we have resolved over many years of experience. As new people come along they seem to become enamored with the bytes, bits, nibbles, line protocols, etc., and so the basic design suffers. Many times these errors are very costly to correct. Examples of such errors are: locating orifice plates too close to elbows, placing turbine meter runs in vertical pipe runs, using asbestos-covered thermocouple wire, etc. This work, which is standard instrument engineering, must be continued along with all the new, more complex technology if jobs are to work correctly.

LOOKING TOWARD THE FUTURE

New modern control system designs are being installed, and they do work, though some do not work as well as we would wish. But there is definite improvement, and in a short time significant changes have been implemented. These projects are quite expensive and engineering-intensive, and at present there is a shortage of this type of engineer. During the present decade of 1980 to 1990, there should be a consolidation of this new technology into more workable maintenance-free, self-checking systems. A real step forward might be taken if all the systems shown in Fig. 2 could be supplied by one hardware vendor so that all interfaces could be taken care of, allowing ground loop and isolation problems to disappear. However this goes, the 1980 to 1990 period appears to be one of great opportunity for the measurement and control field.

2

How to Implement Digital Control

M. J. Sandefur

Implementing complex digital control systems requires careful planning at all stages of project execution. A systems approach to the design, specification, engineering, testing and commissioning of the digital system is essential to the success of the project.

Techniques used to engineer and build a conventional instrumentation system are not directly applicable to the digital project. For the typical analog system, discrete instruments are individually specified, purchased, and then packaged in a customized control panel. Final assembly and testing of the control panel is normally performed by the instrument vendor or a separate panel shop.

The successful digital system project follows a different set of procedures. The instrument engineer must first analyze the system's functional requirements, hardware configuration, software, operator interface and other needs. He or she must scope out the size of his system early in the project, and provide the necessary spare capacity for future expansions that may occur during project execution and later in the field. Basically, the digital control system utilizes common hardware and software to execute indication and control functions which discrete components provide in an analog system. As a result, scope changes to a digital system can be more costly and time consuming due to the interactions of hardware, software and system configuration.

PLANNING A DIGITAL SYSTEM PROJECT

Manpower Requirements. The first step in meeting manpower requirements is to assign a project engineer to the job who is familiar with the design, specification, engineering and execution of digital control systems. Depending on system size and complexity, the project engineer will be required full time during most of the project. Increased demands will be made of the project engineer during advanced stages of engineering, design review, software development, inspections and acceptance testing.

The project engineer will need assistance. For small systems with 500 process points or less, he will require a designer to handle the details of interfacing with the instrument, electrical and architectural disciplines. Numerous drawings, specifications, data base sheets, instrument loop drawings and other documentation must be developed, checked and issued for construction.

For systems with a thousand points or more, the project engineer will require an organized team of engineers, designers and technicians to successfully execute the project. Clear areas of responsibility, goals and milestones must be established for each member. Typically, engineers are assigned responsibility for the different steps in system engineering and design, while the project engineer establishes system configuration, monitors project schedules and costs, interfaces with client and vendor, and in general, maintains control of the project. In all cases, the project engineer must be willing to *delegate authority* or he soon will be lost in details of the job.

Scoping the Computer System. Scoping the system can be one of the most challenging and creative aspects of a computer system project. It is also one of the most critical steps, since everything that follows is built upon it. It is essential that the system be specified as closely as possible at the beginning of the project. Using the system specification, firm prices can be quoted, manpower assigned and manufacturing schedules established. However, none of this can be accomplished unless the project engineer and his client have a clear idea of what the system requirements are.

In general, the client usually has some concept of what is required in the way of computers or digital control systems for his plant. The client may define his requirements to the point of preparing a detailed specification from which the project engineer can obtain