# CHEMICAL ENGINEERING

DECEMBER 8, 1986

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# CHEMICAL ENGINEERING

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# SPECIFYING A BATCH-PROCESS CONTROL SYSTEM

To select a batch control system, you have to weigh its capabilities and costs against the functional requirements of the process.

**David B. Leach**, Air Products & Chemicals, Inc.

Putting automatic controls on a batch process is more challenging than ever: In today's competitive environment, such projects are expected to improve both productivity and quality, and there are more batch-control systems to choose from than there were a few years ago. The systems are also more powerful than they used to be, but choosing the right one is yet a complicated task, one that requires an in-depth understanding of the process as well as the hardware and software alternatives. Trying to gain this understanding can be a frustrating exercise, unless it is done systematically. The aim of this article is to present a systematic approach to specifying batch-process control systems, and to describe the types of systems that are available.

The first and most important step is to define the functional needs of the process — what has to be controlled, and how that can be done. Once these are defined, selecting a particular system is a matter of matching capabilities with the functional requirements — and also weighing such concerns as the cost of the system, and how easily it can be expanded.

## Why batch-process control is difficult

Batch processes can be very complex, and are often poorly understood: What works and what doesn't work is generally known, but *why* things work is often unknown. For instance, batchwise emulsion polymerization has been researched and developed extensively over the last thirty years, yet it is still a formidable task to make a product that meets particular end-use requirements.

Batch control is also quite different from continuous control. For one thing, startups and shutdowns are normal procedures in batch processes, and these require extensive analysis to automate effectively. Another difference is that batch-process variables often cannot be measured online, but instead have to be inferred or analyzed in a laboratory — molecular weight of a polymer is an example. In such a case, developing correlations or means of entering lab data can be difficult.

Batch processes either move from one steady state to another or never reach steady state at all. Because there are so many combinations of possible states, unforeseen interactions among the controllers can occur. Thus a process may constantly be changing, sometimes in unpredictable ways. For this reason, the operators need to keep a close watch on things. Batch-plant control stations have traditionally been located very close to the process, because operators can do a better job of sensing abnormalities if they can see, hear and smell what is going on. Designing a computerized display that provides the same quality of information has been one of the bigger hurdles in automating batch processes.

Whatever the difficulties, the fact is that batch processes can be automatically controlled with a high degree of reliability and safety. But to achieve such a system requires an accurate and detailed understanding of the process's control needs and operational quirks.

## Developing a functional specification

The functional requirements for control should be clearly defined at the inception of the control project, then refined as the job progresses. The means of definition is a document called a functional specification. This document describes the process and system requirements, with enough detail to be used in requesting bids, purchasing hardware and software, and testing the system before startup. Table I outlines the typical content of a functional specification.

Because everything rides on the functional specification, it is a key phase of a batch-process control project. The overall scheme of such a project is as follows:

1. Form a project team of 5–10 members including representatives from the engineering, manufacturing, research, management-information and maintenance departments. This team is responsible for setting the overall control objectives, primary functional requirements, and operational philosophies, and for resolving conflicts regarding the design of the control system.

2. Define the requirements for controlling the batch process, deferring consideration of systems and suppliers until later on. This cannot be done without some knowledge of system offerings, but concentrate on the process measurements and control techniques, and try to disregard the equipment that is going to carry them out. This functional analysis is probably the most time-consuming step.

**Table I** — Functional specifications follow this type of outline

**I. Introduction**
- A. Project objectives
- B. Organizational background
- C. Project background
- D. Scope of work — supplier and buyer
- E. Criteria to be used for selection

**II. Regulatory-control requirements**
- A. Process Area A
- B. Process Area B

**III. Advanced-control and optimization requirements**
- A. Process Area A
- B. Process Area B

**IV. System requirements**
- A. Overall design
- B. Regulatory-control subsystem
- C. Supervisory-control subsystem
- D. Man-machine interface subsystem
- E. Communications subsystem
- F. System redundancy requirements
- G. General system requirements

**V. Project management, testing, installation, and training**
- A. Project organization
- B. Project specifications
- C. Factory testing and staging
- D. Project documentation
- E. Classroom and onsite training
- F. Installation supervision
- G. Startup assistance
- H. Maintenance support

**VI. Optional features**
- A. Regulatory-control subsystem
- B. Supervisory-control subsystem
- C. Man-machine interface subsystem

**VII. Supporting documents**
- A. Batch-control-system configuration diagram
- B. Control-flow diagrams (P&IDs)
- C. Field-signal summaries
- D. Application descriptions and flowcharts

3. Define the other significant needs related to safety, ease of operation, quality control, maintenance, management information, etc. For example, the management-information group may want certain data transferred to their computers. Such data-communications often cannot be retrofitted, and so must be considered in selecting the control system.

4. Review all these items with the project team, and have the team members review them with their own departments — everyone who will have to rely on the system should be comfortable with the specification. Also conduct a preliminary hazard review, and incorporate into the specification any additional requirements that arise out of that.

5. Describe the sequence and logic of controlling the process — using narratives, flowcharts or operational descriptions. A flowchart is best; Fig. 1 gives an example. At this stage, however, there may be not be enough information available to prepare one.

6. Select two or three commercial control systems that best meet the control, safety, and information requirements, and draw a generic configuration diagram that shows the essential architectural features. Figs. 2–4 are configuration diagrams for three generic architectures: programmable-controller based, direct digital control, and distributed control.

7. Define the functional requirements of the control system: continuous-control algorithms (e.g., PID, cascade); batch-control capabilities (sequencing, recipe-handling, interlocking logic, etc.); and communications and display requirements. If the process is large or complicated, it is best to divide it into logical units or groups that can be controlled individually. If recipe capability is needed, describe a typical recipe and how it is to be entered — control systems are often weak in this area.

8. Revise the functional specification so that the control-system requirements are reconciled with the capabilities of the system under consideration. The critical requirements are those that must be met if the project is to succeed — e.g., tighter product quality, ability to manufacture new products, reduced energy usage, increased throughput. Always keep these prime objectives in mind when examining a system's capabilities: Whatever "frills" a system may offer, it is the wrong system unless it can meet the critical requirements that have been laid out for it. Conversely, nonessential requirements can always be dropped if necessary.

9. Begin procurement. Send out requests for quotations based on the new functional specification; evaluate the bids; and select the system and supplier. This selection should be a team decision, to establish a sense of ownership and responsibility among all the groups involved in the project.

10. Reconcile the specification with the capabilities of the specific system selected. Since very few systems will satisfy all of the project requirements, it will be necessary to drop some of the nonessential specifications. On the other hand, new functions can sometimes be added if the system has useful features that had not been considered before. This third issue of the specification should become part of a performance contract between the supplier and the buyer.

11. Begin to design the system in detail: Use the specification to define the basis for software and hardware design; start designing the hardware; and start developing the appli-

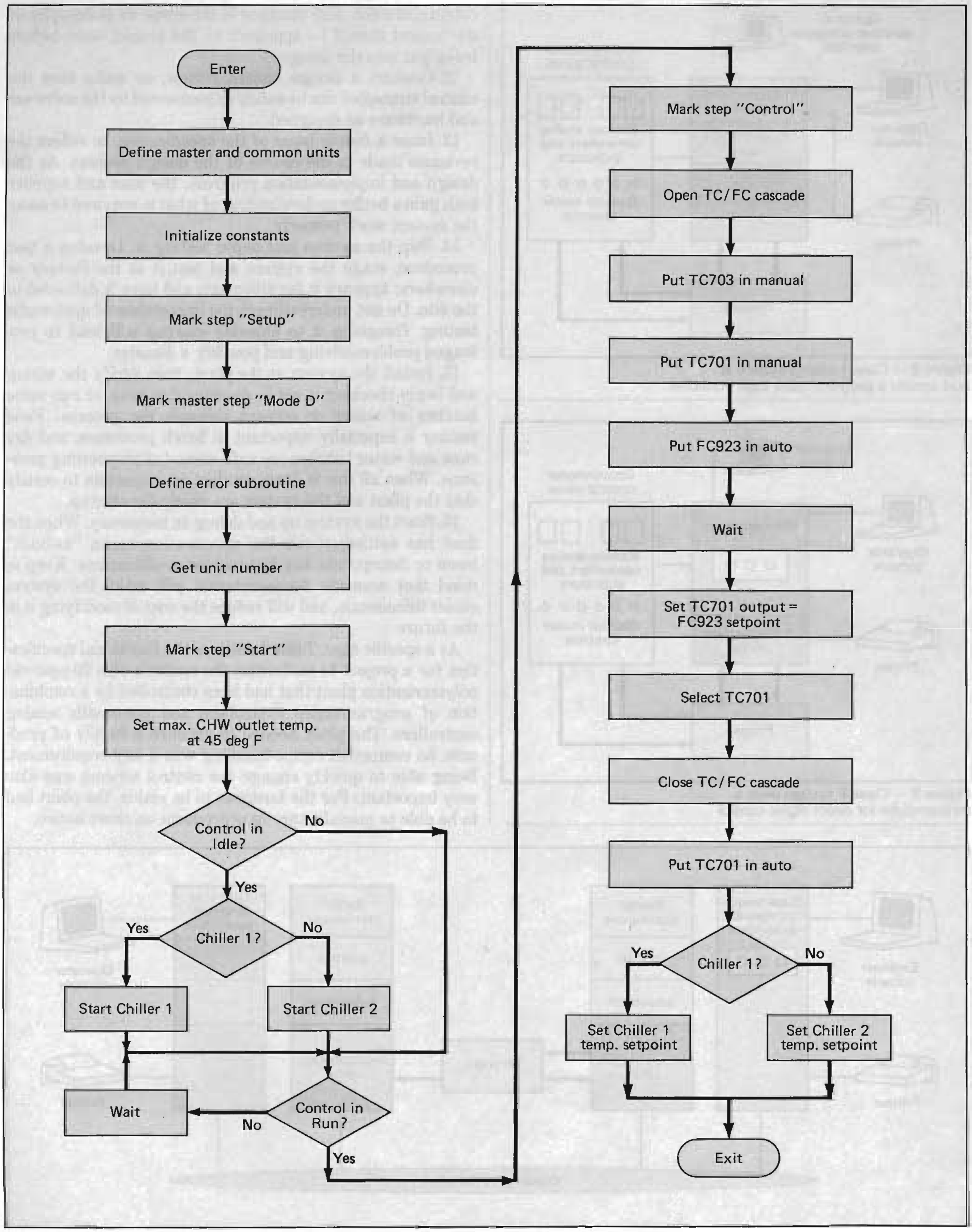



**Figure 1** — Flowchart for starting up a water-chiller reflects the complexity of a batch operation

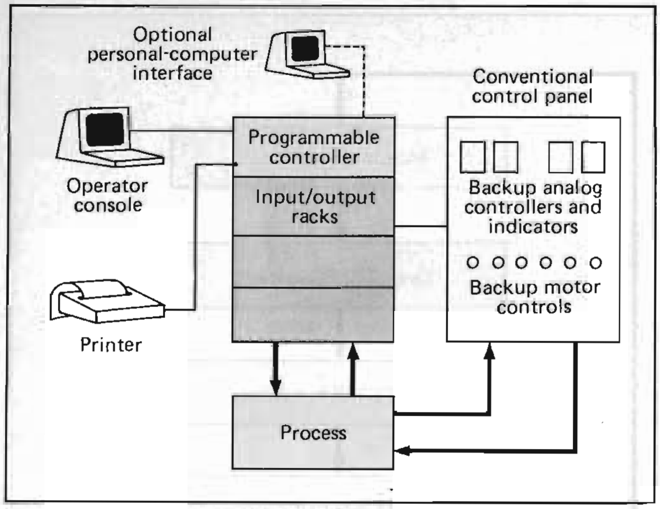



**Figure 2** — Class I control system is built around a programmable logic controller

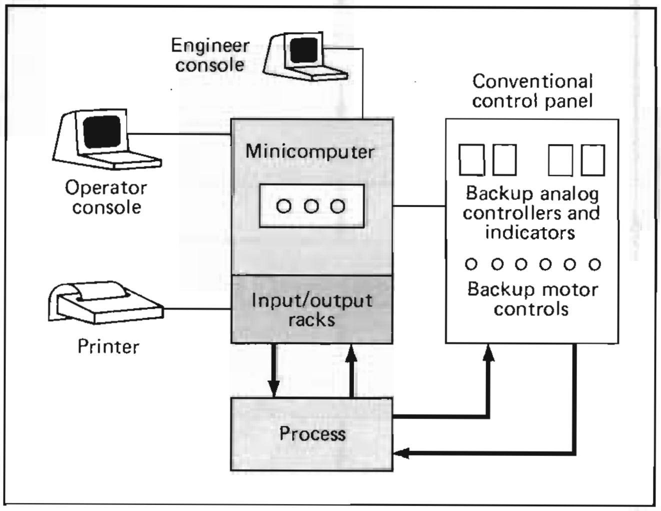



**Figure 3** — Class II system uses a minicomputer for direct digital control

cation software. Any changes in the scope or philosophy of the project should be approved by the project team before being put into the design.

12. Conduct a design hazard review, to make sure the control strategies can be safely implemented by the software and hardware as designed.

13. Issue a fourth issue of the specification, to reflect the revisions made in the course of the design process. As the design and implementation progress, the user and supplier both gain a better understanding of what is required to make the system work properly.

14. Ship the system and begin testing it: Develop a test procedure; stage the system and test it at the factory or elsewhere; approve it for shipment; and have it delivered to the site. Do not underestimate the importance of systematic testing; foregoing it to expedite startup will lead to prolonged problemsolving and possibly a disaster.

15. Install the system at the plant, then verify the wiring and begin checking it out — do some dry runs, or run some batches of water or solvent through the process. Field testing is especially important in batch processes, and dry runs and water batches are safe means of pinpointing problems. When all this is done, conduct an inspection to certify that the plant and the system are ready for startup.

16. Start the system up and debug as necessary. When the dust has settled, revise the specification to an "as-built" issue to incorporate any last-minute modifications. Keep in mind that accurate documentation will make the system easier to maintain, and will reduce the cost of modifying it in the future.

As a specific case: Table I outlines the functional specification for a project to modernize the controls of a 20-year-old polymerization plant that had been controlled by a combination of programmable controllers and pneumatic analog controllers. The plant needed to produce a family of products, so competent recipe-handling was a key requirement. Being able to quickly change the control scheme was also very important: For the business to be viable, the plant had to be able to manufacture new products on short notice.

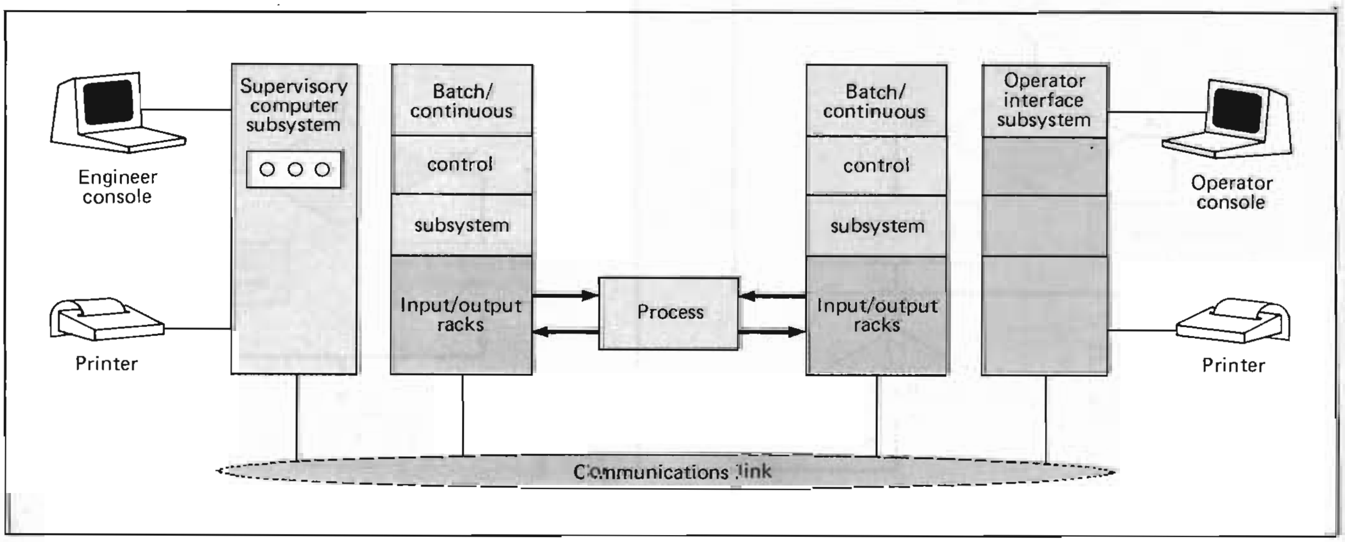



**Figure 4** — Class III system uses distributed microprocessors for batch and continuous control

Once the process-control needs were defined, selecting a system was relatively easy. Flowcharting started immediately after the selection was made; the basis was a control narrative developed as part of the functional specification. Fig. 1 shows one of the flowcharts — describing the sequence for starting up a chiller for the reactor cooling water.

As it happened, factory-testing took much longer than planned, because the system was to be used in ways unanticipated by its manufacturer. Once those problems were resolved, the control software was tested and debugged, using a simulator program. The factory testing was probably the most important phase in the project; it turned up and corrected numerous problems that could have wreaked havoc in the plant. Because of this pretesting at the factory, installation and startup at the plant went very smoothly. The project met its original goals, and has since spawned a number of spinoff projects that make further use of the system's capabilities.

Having considered the general flow of a batch-process control project, let us look at the systems on the market today and how to select the right one for your application.

## Batch-process control systems

The variety of capable control systems has never been wider. There are numerous systems built around microcomputer-based programmable controllers (PLCs). These are considerably smarter than the ladder-logic-only controllers that prevailed a few years ago; today's PLC systems compare favorably with late-1970s minicomputers. The selection of large, computer-based distributed systems is also growing; several new ones are introduced each year. There are also a few direct-digital-control (DDC) systems, in which a single computer handles all the batching functions.

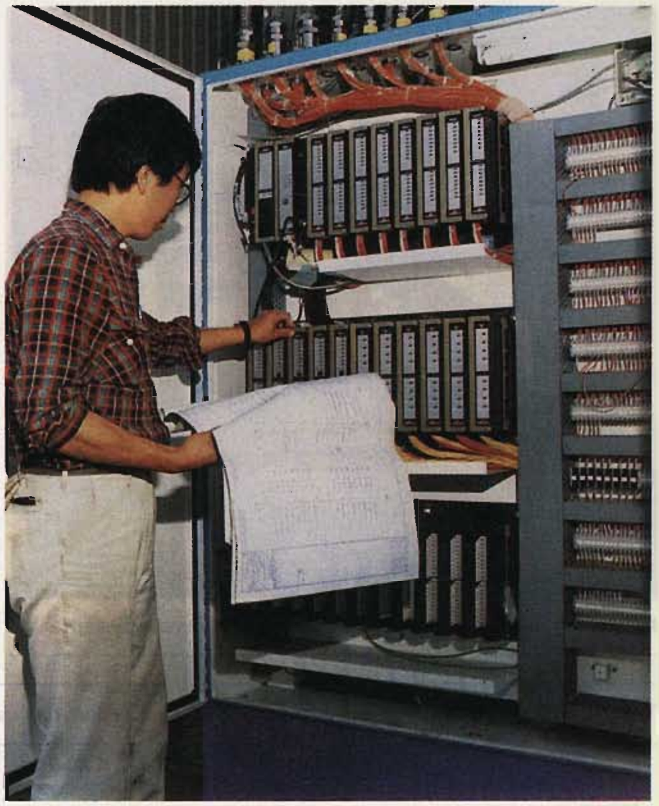
As always, the challenge is to find a system that meets both the project requirements *and* the budget. Control hardware keeps getting better, and from year to year the bottom-line cost changes hardly at all. However, the cost of software development and installation is increasing about 10% per year; software often costs as much as hardware these days.

One can get some idea of the choices by visiting a control-oriented trade show. Unfortunately, it is easy to be overwhelmed with the computer technology and the imaginative claims that vendors make for their systems. How to sort through this profusion of marvelous machines? One thing to do is to classify the systems into generic categories:

Class I. Programmable logic controllers sequence the process and perform a limited amount of continuous control. Analog panel instruments perform most of the analog functions; PLCs are not generally used for analog control, partly because it is hard to access needed parameters in a hurry. Operators oversee things through a CRT console; the PLC may also be connected to a personal computer, which can store process data and perform supervisory functions. Fig. 2 shows a generic architecture for PLC-based control; and Fig. 5 shows a controller with its input/output racks. A large plant may have several such control systems, the PLCs being linked by a data highway with a supervisory computer. Class I systems are most applicable to small- and medium-scale batch processes that have a fixed mode of operation — i.e., ones that are not constantly being changed to accommodate new products and new production tactics.

Class II. These direct-digital-control (DDC) systems use a minicomputer for all the control functions; however, they require analog backup for the regulatory controls. DDC systems are best suited for medium-to-large-scale processes that have fairly complex batching requirements but no need for tight integration between the batch and continuous subsystems. Fig. 3 shows the architecture of a DDC-type batch control system.

Class III. Distributed-computer-based systems use dedicated microprocessors for all the control, communication and display functions. As indicated in Fig. 4, distributed systems handle all the batching and continuous control, and there is no need for analog backup. They are most applicable to medium- and large-scale processes that are fairly complex and that require a tight integration between the regulatory and batch subsystems. Fig. 6 shows the control room for a typical Class III system.



Gould Inc.

**Figure 5** — A programmable logic controller

Deciding which class of system is best, and selecting the particular hardware and software, depends on a number of factors — functionality, speed, physical ruggedness, cost, etc. Table II summarizes the pros and cons of the three types of batch-process-control systems. Let us now look at some of these areas in detail.

## Signal conditioning

Batch-process control involves various combinations of analog and digital signals, often with particular requirements for speed and accuracy. In addition, there is often a need to interface the controls with a special instrument or a "foreign" computer — typically the one that handles the laboratory analyses. All these things can affect the choice of a control system:

What is the nature of the input and output (I/O) signals — are they analog, discrete, or, as is common in batch plants, a mix of both? Class I systems handle discrete I/O very well — better than the other types — but may bog down if required to scan too many analog signals. Also, any system may lack the boards and software options needed to handle the various inputs and outputs with the required speed and accuracy. Pulse inputs and outputs (e.g., from turbine flowmeters or to stepper motors) present problems because there are no standards for them — as opposed to current inputs, for instance, which are standardized at 4–20 mA. Likewise, on/off signals are sometimes treated as second-class citizens by designers of continuous controls; the analog points get all the attention. For instance, a system may be able to display the configuration and maintenance details for analog flowmeters and thermocouples but not for digital motor starters.

Rexnord Automation

**Figure 6** — Control room for a large distributed-control system

Does the process require an intrinsic-safety barrier? If resistance-temperature detectors must be used for reasons of precision, can the system accurately read their low-level voltage signals?

Must the system be interfaced to special analytical instruments or laboratory computers? If just a few analyses per shift need to be entered into the control system, manual entry may be adequate — unless the process cannot wait a few hours for those data. If a direct tie-in is needed, make sure to describe the instrument or computer and its interfacing requirements in the functional specification. Do not expect too much if the vendor says "there are RS-232 ports for such interfaces." All that means is that the electrical cables can be mated; the method of converting the signal from one form to another will still have to be worked out.

Are there any special requirements for speed and accuracy? Digital systems convert analog signals to digital ones with a high degree of accuracy (typically 12-bit resolution) but at various speeds (scan times from 0.06 s to 5 s). Moreover, the scan rate says nothing about how fast a measurement can be displayed on the screen or used for control; in a Class III system, a piece of data may have to travel a very circuitous path. Distributed systems can also have problems in scanning discrete inputs at high speed and in resolving sequences of events. For example, one system scans digital inputs on a ¼-s cycle, but cannot update its database any faster than once per second.

As it happens, the software is often the limiting factor on speed and accuracy. It also determines what kind of control the system can perform.

**Table II** — Each generic type of batch-process-control system has its pros and cons

| Feature | Class I PLC-based[1] | Class II DDC-based[2] | Class III Distributed |
|---|---|---|---|
| Average entry-level cost | \$25 — 50,000 | \$100 — 150,000 | \$150 — 200,000 |
| System size | Small — Medium | Medium — Large | Medium — Large |
| System complexity | Low | Medium | High |
| Continuous control | Poor-Fair | Fair-Good | Very good |
| Sequencing/interlocking | Very good | Fair | Poor[3] |
| Batch control | Poor-Fair | Good-Very good | Good-Very good |
| Advanced control | Poor | Fair | Fair-Good |
| Programming languages | Ladder logic[4] | Medium-level | Higher-level |
| Calculation and reporting | N.A.[5] | Good | Fair — Good |
| Historical trending | N.A.[5] | Fair | Good |
| Redundancy | Easy and inexpensive | Difficult and expensive | Easy and expensive |
| Reliability | Very good | Fair | Good |
| Environmental tolerance | Very good | Fair | Fair |
| Hardware maintainability | Good | Fair | Good |
| Software maintainability | Fair | Good | Fair |
| Computer interfacing | Very limited | Fair but expensive | Highly variable |
| Expandability | Good | Poor | Very good |
| Flexibility | Good | Fair | Very good |

Notes: [1]PLC = programmable-logic controller
[2]DDC = direct digital control
[3]Unless supplemented by a PLC system
[4]Some systems have a Basic-like language
[5]Unless supplemented by a personal-computer system

## Hardware and software

The size, complexity and character of the batch process must also be considered in selecting a control system:

Does the process involve many pieces of equipment with a few steps each, or a few pieces of equipment with many steps? DDC and distributed systems are better suited for handling large numbers of equipment items, but PLC types are perhaps better for executing a sequence of many steps. Will the plant be used extensively for process and product development? If so, the Class III (distributed) system is the most flexible; Class I and II (PLC and DDC) systems are more hardware- than software-oriented, and thus more difficult to expand or change.

Is the operation primarily continuous or discontinuous? Each class of system makes its own compromises in dealing with the two types of control. Class I systems are best suited for primarily sequential operations that do not require sophisticated continuous control — e.g., filtration, packaging. Processes having complicated batch and continuous steps — e.g., emulsion polymerization and PVC production — are better controlled by Class II and III systems. In a DDC system, however, it is difficult to integrate the batch and continuous parts of the process because some of the control functions may be performed by analog devices — i.e., pneumatic or electrical panel instruments. Class III systems are generally the most effective for controlling mixed processes; but individual systems have very different capabilities, and they may be too expensive for small applications.

What level of control is required — regulatory (keep the

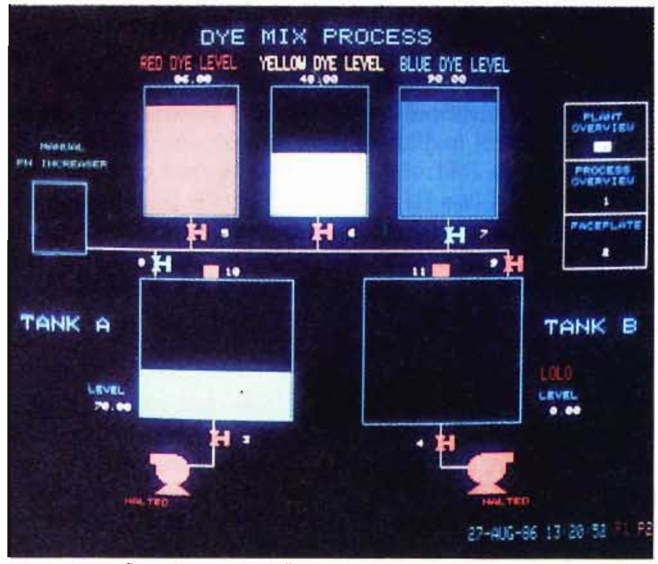



**Figure 7** — Custom graphic displays provide a good overview of the process

**Table III** — Evaluation criteria for selecting a control system for a batch/continuous polymerization plant

| Group | Group features to be looked for |
|---|---|
| **1.0** | **Regulatory-control subsystem** |
| 1.1 | Batch control/multiple units |
| 1.2 | Batch recipe-handling |
| 1.3 | Continuous control/multiple units |
| 1.4 | Sequential logic |
| 1.5 | Interlock logic |
| 1.6 | Preprogrammed control algorithms |
| 1.7 | Flexible signal conditioning |
| 1.8 | Alarming/limiting |
| 1.9 | Real-time trending |
| **2.0** | **Supervisory-control subsystem** |
| 2.1 | Preprogrammed control algorithms |
| 2.2 | High-level programming language |
| 2.3 | Free-format logging and reporting |
| 2.4 | Alarm/function-change history |
| 2.5 | Historical trending/display |
| 2.6 | Operating-system flexibility |
| 2.7 | Statistical-analysis capability |
| **3.0** | **Man-machine-interface subsystem** |
| 3.1 | Ease of database configuration/modification |
| 3.2 | Ease of batch programming |
| 3.3 | Ease of changing batch recipes |
| 3.4 | Ease of cold restart |
| 3.5 | Preformatted displays |
| 3.6 | Custom-graphic-display capability |
| 3.7 | Operator-station operability/flexibility |
| 3.8 | Engineer-station operability/flexibility |
| 3.9 | Database-access security |
| **4.0** | **Communications subsystem** |
| 4.1 | High-speed link |
| 4.2 | Full redundancy |
| 4.3 | Communications security |
| 4.4 | Self-diagnostic capability |
| 4.5 | Flexible device-handling |
| 4.6 | Networking capability |
| **5.0** | **General system requirements** |
| 5.1 | Unified database structure |
| 5.2 | Fast point-scanning |
| 5.3 | Capable of processing large number of points |
| 5.4 | Secure emergency-shutdown provisions |
| 5.5 | Intrinsic-safety compatibility |
| 5.6 | Rugged input/output hardware |
| 5.7 | High-integrity cabinets and consoles |
| 5.8 | Nonrestrictive electrical requirements |
| 5.9 | Nonrestrictive environmental requirements |
| 5.10 | State-of-the-art computer hardware |
| 5.11 | State-of-the-art computer software |
| **6.0** | **Expandability and flexibility** |
| 6.1 | Regulatory-control subsystem |
| 6.2 | Supervisory-control subsystem |
| 6.3 | Mass storage and peripherals |
| 6.4 | Operator interface |
| 6.5 | Mainframe-computer communications |
| 6.6 | Remote engineering/troubleshooting |
| 6.7 | Laboratory-computer communications |
| **7.0** | **Maintenance and reliability** |
| 7.1 | Negligible effect of component failure |
| 7.2 | Effective hardware-maintenance training |
| 7.3 | Effective software-maintenance training |
| 7.4 | Extensive hardware and software diagnostics |
| 7.5 | Long-term hardware support |
| 7.6 | Long-term software support |
| 7.7 | Readily accessible spare parts |
| 7.8 | Remote diagnostics by supplier |
| **8.0** | **Supplier qualifications** |
| 8.1 | Extensive batch-process control experience |
| 8.2 | Extensive continuous-process control experience |
| 8.3 | Extensive systems-engineering and design capability |
| 8.4 | Experienced applications-programming staff |
| 8.5 | Aggressive quality assurance/testing |
| 8.6 | Quality educational facilities and training program |
| 8.7 | Favorable track record in performance and support |
| 8.8 | Similar systems previously installed |
| 8.9 | Similar processes previously automated |

plant running), advanced (run it well), or optimizing (run it profitably under changing conditions)? Class I systems are good at regulatory control, but are generally not sophisticated enough for advanced control. Class II systems are good at advanced control and lower-level optimization, but for reliable regulatory control they must be backed up by analog systems. Most Class III systems can handle both regulatory and advanced control, but a need for such functions as batch scheduling and automatic recipe-loading narrows the field considerably. When it comes to plantwide optimization, there are still fewer choices.

## Operator interfaces

Batch-process operators need fast access to a wide variety of process and non-process information in order to do their jobs effectively. Custom schematic displays such as the one shown in Fig. 7 are useful for providing an overview of the process. However, operators more typically rely on standard preformatted displays — such as group displays or simulated instrument faceplates — because these are easier to comprehend and to manipulate, especially in a tense situation.

Interfaces vary widely among batch-process-control systems. Most PLCs now offer video-monitor displays, generated either by a monitor tied to the controller or by a personal computer, as well as conventional panel displays. However, such interfaces can fall short in the types of information that can actually be controlled. Class II and III systems generally have better interfaces, which is one reason for their higher initial cost.

How many monitors and printers are required for effective operation? A good rule of thumb is that each control-room operator should have at least one video terminal and one hardcopy device such as a printer or video copier, and these devices should be organized into workstations whenever possible. As for deciding on what to display, it is important to find out what kind of information the operators and shift supervisors actually use, and how they want it delivered. Consider not only the routine operating conditions, but also emergency procedures, scheduling, recipe-handling and maintenance. Also keep in mind that creating displays and maintaining the control database will tie up a terminal at times; for this, and for programming, a separate engineer's terminal can often be justified.

## Database considerations

All three classes of control system maintain information on the points to be monitored and calculated, the control and communication functions to be executed, and the actual values of the input and output signals for some period of time. Maintaining and modifying this database is one of the key engineering-support activities for batch systems, and for this reason it is certainly worthwhile to consider the nature of the database when selecting a system.

Distributed systems tend to have the most complex database structures, and therefore require the most support. One key feature to look for is whether the system has a "unified" database, with which a change in any parameter is automatically and immediately reflected throughout the system. Without this, the engineer will have to build and maintain separate databases for the various control devices, which may lead to inconsistencies. Newer distributed systems tend to have unified databases. However, marrying PLCs to such systems can still cause problems, because this introduces separate databases and separate programming languages.

What are the requirements for storing historical data? Such data may be needed for displaying trends, producing reports, and running statistical-analysis programs. Class I systems generally have very little storage capability — but a personal computer could help fill that function. Entry-level Class II and III systems tend to be marginal in this area, but they can generally be equipped with mass-storage devices. In that case, storage and display of historical trends is easily accomplished. However, additional computing power may be needed if the data are to be used for optimization or statistical process control.

Will the system need to be expanded or upgraded in the future? Consider which way the plant and the controls will be headed for the next five years or so. Class I and II systems may be difficult or expensive to expand, since they partially depend on panel instruments and may be restricted by memory size or processor capability. Class III systems are much easier to expand, since they are modular and decentralized. However, upward migration can be a problem with any class of system because the technology is changing so rapidly: When it comes time to expand, will it be possible to upgrade the supplier's equipment, or will the equipment have to be thrown away because it is obsolete? Will it also be possible to effectively integrate the new components with the old ones?

## Conclusions

Table III is an example checklist of things to look for in choosing a supplier and a particular system. To use this, one could assign a weight to each requirement, and score each system on how well it meets that requirement. Adding up the weighted scores will provide a reasonable means of comparing systems.

Still, the essential thing is to make sure that the system selected meets the prime objectives of the project. To do this, it is necessary to define the process and system needs, and communicate them clearly to the supplier.

The importance of this front-end analysis cannot be overemphasized. Based on personal experience with three recent batch-control projects, I can safely say that these projects would have floundered had we not put together a detailed functional specification. In fact, we really should have analyzed the control procedures in greater detail, because in the testing phases we found a number of quirks that called for some redesign and reprogramming.

***Mark Lipowicz**, Editor*

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