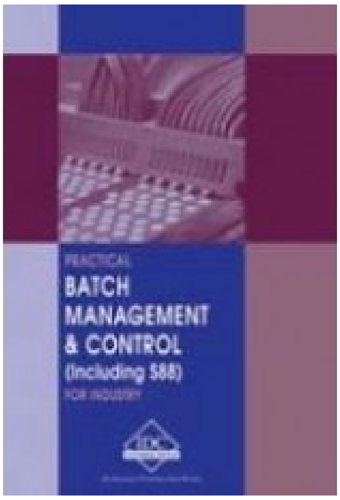
BA-E - Batch Management & Control (Including S88)



Price: $139.94

Ex Tax: $127.22

Short Description

This manual aligns with current practices in the automation of batch processes, including the drive for integration with MES and ERP products from major IT product companies. References and examples are drawn from DCS/PLC batch control products in the market place.

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Table of Contents

Download Chapter List

Table of Contents

First Chapter

Introduction to batch management and control

1. Introduction

1.1 Introduction

The manufacturing industry has drawn its efficiency from large-scale continuous processes over a long period. Initially, the manufacturing facility for a new product used to be either a batch process or a laboratory process on a larger scale. But as the economy of scale was key to success in business, chemical engineering and process industries focused all attention on designing and developing continuous processes. Continuous processes are dominant in manufacturing of bulk chemicals. However, for manufacturing fine & specialty chemicals, with the increased emphasis on and customer requirements of high quality, equal focus has been on batch processing. Today, almost half of the processes in industry are batch processes.

Following are the economic and technical factors that make batch processes favorable over continuous processes:

- Batch processes often consists of simple processing units like mixers and stirrers
- A batch processing unit may be multipurpose - it may be used for several processing phases of the batch and could support multi-product manufacturing within the facility
- Batch manufacturing plants are comparatively more robust than a continuous plant
- Batch process manufacturing facility is easier to scale up depending on market demand and requirements

1.1.1 Classification of processes

Industrial processes are classified depending on the output of the process as:

- Continuous process
- Discrete process
- Batch process

Continuous process

In a continuous process, there is continuous flow of material or product. Processing the materials in different equipment produces the products. Each equipment operates in a single steady state and performs specific processing function.

Some examples of continuous processes are - generation of electricity, Cement/ Clinker production, paper mill, and so on.

Discrete process

In a discrete process, the output of the process appears one-by-one or in discrete quantities. The products are produced in lots based on common raw materials and production history. In discrete process, a specified quantity of products moves as a unit or group of parts between workstations.

Some examples of discrete processes are - assembly of watches, production of cars, assembly of Television Set, etc.

Batch process

In a batch process, the output of the process appears in quantities of materials or lots. A batch process has a beginning and an end. Batch processes are neither continuous nor discrete, but have characteristics of both. Batch process is usually performed over and over. The product of a batch process is called a batch. Batch processes define a sub-class of sequential processes. Batch processes generate a product but the sequential processes need not necessarily generate a product.

Some examples of batch processes are - beverage processing, biotech products manufacturing, dairy processing, food processing, pharmaceutical formulations and soap manufacturing.

1.2 Identification of batch processes

A batch is defined as:

- The material that is produced by a single execution of a batch process, or
- An entity that represents the production of a material at any point of time in the process

Here, it is important to note that the term "**batch**" means both the material produced by and during the process, and also an entity that represents the production of that material. The term batch is used as an abstract contraction for the words - the production of a batch.

We have seen classification of processes based on their outputs. Now we will formalize the definition of a batch process:

- A process is considered to be a batch process if, due to physical structuring of the process equipment or other reasons, the process consists of a sequence of one or more steps that must be performed in a defined order. And, on completion of the sequence of the steps a finite quantity of the finished product is produced. The sequence is repeated to produce another batch of the product
- A batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input raw materials to an ordered set of processing activities over a finite period of time using one or more equipment

1.2.1 Batch processes

Today many products are produced using continuous processes that were originally produced using batch processes. The main reason behind the shift from batch process to continuous process was that the batch processes were labor intensive and required skilled & experienced operators to produce batch products with consistency in quality. However, due to increasing demand for flexible and customer-driven production, batch processes find equal importance in manufacturing industries. Batch processes are economical for small-scale production as it requires few number of process equipment and intermediate storage is inexpensive. Batch processes are suitable for manufacturing of large number of products or special products due to flexibility in manufacturing process equipment.

Nature of batch processes

Batch processes have the following characteristics:

- Batch processes deal with discrete quantities of raw materials or products.
- Batch processes allow the tracking of these discrete quantities of materials or products.
- Batch processes allow more than one type of product to be processed simultaneously, as long as the products are separated by the equipment layout.
- Batch processes entail movement of discrete product from processing area to processing area.
- Batch processes have recipes (or processing instructions) associated with each load of raw material to be processed into product.
- Batch processes have more complex logic associated with processing than is found in continuous processes.

- Batch processes often include normal steps that can fail, and thus also include special steps to be taken in the event of a failure.

Nature of steps involved in a batch process is:

- Each step can be simple or complex in nature, consisting of one or more operations.
- Generally, once a step is started it must be completed to be successful.
- It is not uncommon to require some operator approval before leaving one step and starting the next.
- There is frequent provision for non-normal exits to be taken because of operator intervention, equipment failure or the detection of hazardous conditions.
- Depending on the recipe for the product being processed, a step may be bypassed for some products.
- The processing operations for each step are generally under recipe control, but may be modified by operator override action.

A typical batch process step is shown in the Figure 1.0.

Figure 1.0

Typical batch process step

1.2.2 Classification of batch processes

Batch processes can be classified on the basis of two criteria:

- The quantity of output produced
- The structure of batch process plant

The number of products produced:

- **Single product batch process:**Same amount of raw materials are used and same operations are performed on each batch to produce same product
- **Multi-grade batch process:**Same operations are performed on each batch with different amount of raw materials and/or under different processing conditions to produce similar but not identical products
- **Multi-product batch process:**Different methods of operations or control

are performed on different amount of raw materials under different processing conditions to produce different products

The structure of batch process plant

- **Single-path batch process:** In a process with single-path structure, the batch passes sequentially in a predefined path from one to another unit as shown in the Figure 1.1(a)
- **Multi-path batch process:**In a process with multi-path structure, there may be several batches active at a time and the equipment may be of different physical characteristics. For example, as shown in the Figure 1.1(b), a reaction operation may be handled by one unit in one path of the process and by two units in the other path of the process.
- **Network batch process:**In a process with network structure, the sequence of the units may be pre-assigned, or determined prior to execution of the batch or during the execution of the batch. In network structure process, an appropriate path is determined at the time of execution depending on constraints like recipe requirements and equipment capabilities. A typical network process is shown in the Figure 1.1(c). Control of network process is complex due to the need for allocation of equipment and the arbitration of requests for the equipment.

Figure 1.1

Classification of batch processes based on structure of the plant

Whatever be the structure of a batch process plant, the nature of the batch process involved and the types of equipment used or the operations involved, the objective is to manufacture batches of product. As discussed above, there are many variations—single plant, single and multi-stage processes, etc. Whatever the plant configuration, consideration of any single batch reveals that a series of operations in a dedicated vessel or train of vessels according to some recipe always processes it. Hence, the starting point for developing a methodology for batch process control is to identify distinct products or generically similar products. After identification of products, for each product the route that a batch follows through the plant is to be established, and the operations carried out on that batch considered, i.e. which operations, where and in what order. Analysis of the structure of a batch plant gives a good insight into the nature of both the operations and the control requirements. The structure relates to the number and type of process streams, and to the trains of equipment used. A plant may be considered as a process cell consisting of a cluster of units and equipment modules within which the process stages are carried out. These units and equipment modules are organized either in series and/or in parallel. A stream is defined to be the order of units and equipment modules used in the production of a specific batch. Or in other words, a stream is the route taken through the plant by a batch. A train consists of the units and equipment modules used to realize a particular stream.

The complexity of a batch processes plant based on the process structure and number of products is shown in the form of a matrix as shown in the Figure 1.2. The matrix indicates the degree of complexity involved in automation of various combinations. More complex a process, more it requires allocation, arbitration and batch management solutions. More the number of products being manufactured by a process more are the need for recipe management and batch management solutions. A single-product, single-path batch plant is simple while a multi-product, network-structure is the most complex combination.

Figure 1.2

Complexity of batch process plants

Example 1.1:

A simple example of Batch process can be taken from Fiber-Cement Products industry, wherein Fiber, Cement, Pulp and additives are used in different proportions to prepare Raw Material Slurry Batches for making corrugated roofing and flat boards. A typical P&ID for the batch process is shown in the Figure 1.3(a). The Raw Material Preparation Batching system can also be used to prepare slurry for Fiber-Cement High pressure pipes.

Figure 1.3(a)

Example of batch process - Preparation of raw materials slurry in fiber-cement products plant

Example 1.2:

Another example of a batch process as shown in the Figure 1.3(b) is a simplified plant for batch production of industrial ethanol. The ethanol is produced as a result of the biodegradation of glucose by yeast in a fed-batch mode. The plant consists of three fermentors, three product tanks, a feed tank, a sterilizer, pumps and valves.

Figure 1.3(b)

Example of batch process – production of industrial ethanol.

Example 1.3:

An example of network structure in a brewery plant for fermentation batch process is shown in the Figure 1.3(c). The plant consists of several high volume tanks that are interconnected by a complex network of pipes, valves and pumps. One of the processes taking place is fermentation of the worth. The brewing tanks deliver the worth to the fermentation tanks. After fermentation, the 'green beer' is pumped to aging tanks. Filling and emptying of a fermentation tank takes several hours and the fermentation process itself takes several days. The tanks are divided into clusters as shown as an example in Figure 1.3(c). There are several shared resources in the system; many tanks share the same pipes, pumps, cleaning equipment, and processing equipment. Figure 1.3(c) illustrates groups of three-fermentation tanks that share the same pipe. This means that only one of these three tanks can perform an action using the pipe at the same time. Some actions are filling, emptying, and cleaning.

Figure 1.3(c)

Example of network structure batch process – fermentation process in a brewery plant

Figure 1.3(d)

Example of batch process for producing various types of Cookies

Example 1.4:

An example of batch process with time-based operations that produce various types of Cookies is shown in Figure 1.3(d). Let us consider that the chocolate-chip cookies are made in the first production run. First, the oven is turned on to the desired temperature. Next, the required ingredients in proper quantities are dispensed into the sealed mixing chamber. A large blender then begins to mix the contents. After a few minutes, vanilla is added, and the mixing process continues. After a prescribed period of time, the dough is in proper consistency, the blender stops turning, and the compressor turns on to force air into the mixing chamber. When the air pressure reaches a certain point, the conveyor belt turns on. The pressurized air forces the dough through outlet jets onto the belt. The dough balls become fully baked as they pass through the oven. The cookies cool as the belt carries them to the packaging machine. After the packaging step is completed, the mixing vat, blender, and conveyor belt are washed before a batch of raisin-oatmeal cookies is made. Products from foods to petroleum to soap to medicines are made from a mixture of ingredients that undergo a similar batch process operation.

1.3 Background of need for integrated batch systems

There are significant requirements for data transfers between the batch process operations management system and other information systems. This data is used for calculations, tracking, and for validation that expected events have occurred. Normally, the following systems need to be integrated with batch systems:

1.3.1 ERP systems

Many batch process plants install comprehensive and integrated Enterprise Resource Planning (ERP) Systems. These systems provide financial reporting, order entry, warehouse monitoring, and shipping capabilities. They do not replace the operations management systems. The operations management system is required to provide the validated production data required for the ERP system. The ERP system will download customer order data and average raw material requirements. These are translated into specific scheduled grade productions and shipments by the operations system. The operations system also transfers the reconciled production data for long-term storage to the ERP system.

1.3.2 Maintenance systems

Integration of the maintenance system with the operations management system is important for tracking equipment utilization and to coordinate time information of equipment in-service and out-of-service.

1.3.3 Lab systems

For quality assurance and quality control of products, close integration of the operations management system with the laboratory system is required. Product samples and quality measurements are time-stamped and stored with other batch data.

1.3.4 Supply information system

Raw material quantities and qualities that have been recorded by the operations system are compared and balanced to those reported through the supply system to identify discrepancies.

1.3.5 Distribution information system

Shipment quantities and qualities are calculated by the system and are compared to those reported by distribution systems.

The batch process and its control have evolved over a long period of time from mechanical devices used to regulate the levels in liquid tanks, followed by pneumatic controls to the modern electronic controls based on microprocessors based controllers and expert control systems. With the availability of sophisticated measurement sensors, advanced control systems and reliable communication technology, the demand for integrated control systems has increased. With the use of computers and software based control algorithms - use of complex control algorithms apart from conventional PID control, ratio control, cascade control, etc. has increased in manufacturing industries including that for batch processes control. Now a days, computer based control systems are used for process control and optimization of processes. A computer has capabilities to monitor, compute and analyze multitude of variables and take multiple actions simultaneously.

Process automation helps in managing processes in all process conditions. Control systems help in coordination of activities of the entire process and respond to dynamic changes in the process. With the help of artificial intelligence based expert systems, it is possible to optimize a process and manage it without manual interventions. Integrated batch automation systems provide process control closer to the ideal expectation of the operator with highest flexibility.

As shown in the Figure 1.4, adoption of integrated batch management system as per the ISA S88 standard requires discipline but provides modular approach, reduces complexity and increases the flexibility of the process.

Figure 1.4

Process capabilities with integrated automation

To meet the increasing demand for integrated batch control systems, batch control models are combined with information models to cater to the needs of batch plant information. The main objective of an information model is to establish a proper framework for information management systems that support integrated batch plant operations.

In the 1980s, the Computer-integrated-manufacturing (CIM) model represented use of information technology in manufacturing. The CIM model represented process control system devices to the business systems. But then organizations moved towards de-centralization and Flat organization structures. Therefore, hardware based CIM model became obsolete and software based CIM model with 3 levels as shown in the Figure 1.5 was evolved. The top most level of the model pyramid was the strategic level constituting strategic planning and included business functions like - Sales, finance and manufacturing resource planning. The middle level constituted tactical level comprising of plant management functions like - process, production, maintenance, resources and quality management. And the bottom level was operational level that covered the process control and the manufacturing control functions.

Figure 1.5

Computer-integrated-manufacturing (CIM) model levels

1.4 Overview of batch systems engineering

For a batch process (or any other process), the process lifecycle is always longer than the life cycle of the automation system. Normally, a process outlives the automation due to fast developments and advancement in the field of automation and process control technologies. During a process life cycle there may be several generations of automation as shown in the Figure 1.6. Depending on process life cycle and process requirements, it is at times necessary to decommission the obsolete system and upgrade it with the latest generation of automation systems.

Figure 1.6

Automation life cycles during process life cycles

Automation upgrades have become increasingly important in the industrially developed world, where many aging control systems exist. Though functioning satisfactorily for years, many of these systems don't meet today's need of sophisticated control, historical recording for traceability, human-machine-interface, and supply chain synchronization. These outdated systems need to be replaced by modern batch control systems, on open platforms to achieve current regulatory requirements and current business performance needs.

Improving operational efficiency is fueling the growth. Manufacturing efficiency and flexibility is key to meeting the needs of powerful mass merchandisers. The consumers demand more variety and best quality. To maximize business performance, a manufacturing company has to optimize its production plants along with its enterprise and supply chain domains. The need to optimize the supply chain is increasing the need for real-time plant and production information, which is fueling the growth of manufacturing automation and its integration to business system. Offering optimization at all levels is no longer sufficient for an enterprise to have islands of automation along with isolated supply chains. To maximize the potential of batch production, manufacturing plants and supply chains need to work together in an optimized fashion. In such environment, manufacturing must continue to maintain its central role, but enterprise-wide optimization of production facilities and supply chains are equally important for maintaining the bottom line. Manufacturing enterprises are optimizing not only their production plants but also their enterprise and supply optimization. Manufacturers used to be satisfied when control loops were properly tuned, recipes, phases ran in proper order, and products were produced to their required quality specifications. With today's global environment, increased competition, and the need for custom products, enterprise, and supply chain optimization are becoming increasingly important.

As shown in the Figure 1.7, the strategic batch automation/system project engineering has six phases:

- Definition of requirements
- Design
- Implementation
- Testing and start-up

- Continuous evaluation and improvement
- Decommissioning

Figure 1.7

Phases of batch automation/system engineering

Definition of requirements

In the first stage, the batch automation/system objectives are clearly identified and defined. The requirements defined must be communicated to all the members of the team and must be understood by all.

Following are the main objectives of defining the requirements:

- Document the scope of the batch process
- Develop the objectives for the batch process that are specific, measurable and achievable
- Develop the objectives for the batch automation system that are specific, measurable, achievable and aligned with the objectives of the batch process
- Define the parameters, against which the performance of the project will be evaluated
- Begin with a clear cut target in mind
- Involve all the team members

Design

During design, the operational specification is written without any mention of the platform or how the control programming is to be done. The operation of the process is defined based on the process capabilities and not based on the product needs. The ISA SP88 standard clearly distinguishes between the process and the product, i.e. between equipment and the procedure. For existing process, P&IDs can be designed during this phase otherwise design should be done with PFDs. During design phase, it is defined how the P&IDs should be organized and the measurement and output needs of the process. The system and the software to be use are also defined. During the design phase, after all the required inputs are available, safety and Hazard analysis and operability studies can be also be conducted.

Following are the main objectives of design phase:

- Modularize process
- Define operational requirements based on which operational specification will be prepared
- Simplify and optimize process
- Define strategy for Alarm management system
- Define process communication
- Define system requirements based on which the system specification will be made
- Selection of system based on system requirements

Implementation

During implementation phase, the process design activities like preparation of layout, piping design and for a new process P&IDs are developed. Depending on the requirement, construction also takes place during this phase. The batch automation system is designed and implemented during this stage. The control system is configured based on the process requirements and programmed to perform the desired tasks. Implementation of control strategies is documented.

Following are the main objectives of the implementation phase:

- Implement the control strategies as defined during design phase
- Develop man-machine-interface
- Create system qualification acceptance criteria
- Documentation of control strategies

Testing and start-up

The automation system is installed and tested as per the plan and procedure defined during the design and implementation stages. Simulation techniques are used for testing before startup. After successful testing, next step is to start-up the process. If required, process validation is also done during this stage.

Following are the main objectives of this phase:

- Carry out simulation
- Test the control strategies as defined during the design and implementation stages

- Train the operators
- Deliver a batch control/management system that works

Continuous evaluation and improvement

During this phase the system is operational. The performance of the system is monitored and evaluated continuously and improvements are carried-out in the system after re-evaluation of previous phases.

The main objectives of this phase are:

- System assurance
- Continuous up gradation of system
- Backup of the system

Decommissioning

The system is decommissioned and removed if the system becomes obsolete and is to be removed or any major changes are required in the process. Before decommissioning, all previous phases must be evaluated for the necessary changes. System documentation is updated.

The main objectives of decommissioning phase are:

- Evaluate all previous phases for impact of changes to be made
- Evaluate impact on upstream and down stream processes
- Update system documentation

1.5 Introduction to standards

Why was the need felt for Batch management standard?

- No universal model existed
- Confidence that such a model could be created
- Help understand the big picture
- Tie in the details with the big picture
- Allow better communications
- Among staff
- With vendors
- Reduce risk WRT planning, costing and project management
- Basis for better documentation
- Allow for simulation

1.5.1 The Instrument Society of America (ISA) S88 standard

The S88 standard was approved by the Instrument Society of America (ISA) in 1995 and later adopted as an IEC standard (IEC 61512-1). The S88 standard establishes a framework for the specification of requirements for batch process control, and for their subsequent translation into application software. The framework consists of a variety of definitions, models and structures.

Part 1 of the S88 standard on batch control defines a consistent set of terminology and models for defining and describing the control requirements for batch manufacturing processes/facilities. The SP88 Standard Committee had developed the ISA S88.01 standard that provides batch manufacturers methods and tools required to analyze the existing batch processes and add new products. Today, batch control systems based on ISA S88 standard models are readily available for use with software packages.

The objectives of S88 standards are:

- To provide a common, consistent model for design and operations of batch manufacturing processes/facilities and batch control systems
- To continuously improve controls and efficiencies in batch manufacturing processes
- To improve communications

The S88 standard terminology and models help you to define the available equipment, recipes and the steps involved in batch manufacturing of products. There are 4 types of models given in S88 standard. These are:

- **Physical Model:**Used to define the hierarchy of equipment used in the batch manufacturing process/facility
- **Control Activity Model:**Used to define the relationships between various control activities required for batch processing
- **Procedural Control Model:**Used to define the control that enables the equipment to perform a task
- **Process Model:**Used to define the results of performing procedural control on the equipment in the batch process

Figure 1.8 illustrates relationship between ISA S88 standard model and terminology. These models will be discussed in details in next modules.

Figure 1.8

ISA S88 standard models and terminology

The S88.01 standard contains 6 sections:

- Scope
- Normative references
- Definitions
- **Batch processes and equipment:**This section describes a physical model consisting of equipment objects - enterprise, site, area, process cell, unit, equipment module, and control module as shown in the Figure 2.1.
- **Batch control concepts:**This section deals with concept of basic, procedural and coordination control. This section describes, procedural control model, which is made up of procedural entities like - procedure, unit procedure, operation and phase. This section defines four types of recipes, namely - General, site, master and control recipe. Production plans & schedules, resource allocation, production information, modes & states and exception handling are also included in this section.
- **Batch control activities and functions:**This section describes the functions and activities necessary to make the pieces defined in Section 4 and 5 works together. This section is based on the control activity model.

ISA S88 standard Part-2 defines the relationships described in the control activity model of S88.01 standard and the data passed between those activities through data modeling. The scope of S88 Part-2 is:

- To provide a data model that represents the recipe, batch schedule, batch history, and equipment objects
- To provide data exchange formats for recipe, schedule, history and equipment objects
- To define language guidelines to support data exchange of components of S88.01
- To define language guidelines for user representation of procedural elements

Part 1 and Part-2 of the standard provide an environment for open data exchange between the objects defined in part 1 and data exchange between these objects and the business world. S88.02 ensures that the methods maintain uniformity and provide a common base for vendors. The data models of ISA 88.02 provide a starting point for developing interface specification for software components directly involved in batch control. However, just adherence does not ensure interoperability, but it does reduce the task of making systems work together to relatively simple task of deciding on technical exchange format. The data models also provides view of data involved in batch control in a standard format that can be used by software systems not directly related to batch control, such as Management Information Systems (MIS), ERP systems, Preventive Maintenance Systems, etc.

Recently ISA S88 standard Part 3 has been formulated and accepted. Part 3 of the ISA S88 standard provides the detailed definition of the content of a general recipe, information format, procedure to write it down so that it is understood universally, and a methodology of a conversion of a general or site recipe to a master recipe. Conversion of general/site recipe to master recipe enables to have a single corporate-wide recipe for a product that can be manufactured at various manufacturing facilities with consistent quality assurance.

The ISA S88 standard represents a major step forward for batch process control; it establishes a framework that addresses a variety of complex issues. Defining terminology and relating it to meaningful models removes the ambiguity. The structures involved lead to the development of more comprehensive specifications, which consequently lead to better quality application software. The control system manufacturers and suppliers evaluate and review the control functions and structures of their systems to ensure conformance with the S88 standard requirements. Suppliers develop tools to enable users to articulate their requirements in terms of S88 objects and constructs, and for those requirements to be translated automatically into application software. Detailed decomposition of the various activities goes a long way to this end. Unlike most of the standards, which are retrospective in the sense that they attempt to provide a reference based on presently accepted good practices, the ISA S88 standard models and structures provide a flexible framework with much scope for context based interpretation and application.