

PETER L.GINN

BASICS OF COMPUTERIZED PROCESS CONTROL FOR CHEMICAL ENGINEERS

#### PETER L. GINN

# PROCESS CONTROL AND DIGITAL MINICOMPUTERS

To my own personal editor, Ann Clotilde, without whose drawings and typing this book would not be.

## An Introduction to PROCESS CONTROL AND DIGITAL MINI COMPUTERS

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## AN INTRODUCTION TO PROCESS CONTROL AND DIGITAL MINICOMPUTERS

### **PREFACE**

This book's major purpose is to familiarize chemical production engineers and managers of chemical process plants with the unfamiliar task of controlling a chemical process by means of a digital computer. No previous knowledge of digital computers is assumed. Two chapters are included, intended for chemical engineers, which explain the terminology, the architecture, and the overall operation of computer systems. Another purpose of the book is to help electrical and electronics engineers, and computer programmers likewise involved with such tasks, to familiarize themselves with chemical process plants. For non-chemical engineers, two chapters are included which cover simple, conventional instrumentation, the elements of flow control, and the description of a chemical process.

There is no *best* way to construct, operate, and control a particular chemical process. Consequently, the methods presented in this book are not to be held as definitive, but are offered as a stimulus to practitioners, as guidelines to novices, and as representative of one complete exercise to the uninitiated.

The process described is the "Witches' Brew Process," a process that not too many people are aware exists. As no reader has preconceived notions about how this Transylvanian process should be designed or controlled, all readers should be able to concentrate on the implementation of digital computer process control rather than the process itself.

Peter L. Ginn April 1982

## INTRODUCTION

You are reading this book because you are interested in automating a chemical process with a programmable processor. Perhaps you are a chemical engineer who already has an approved computerization project scheduled, or installed, and you are casting around as how best to proceed. You are not sure what resources it will demand, or how to check on progress; perhaps you feel imaginative solutions might be feasible if only you knew how. On the other hand, you may have no experience in this field of endeavor and no immediate plans but are curious about chemical process automation with programmable processors. Perhaps most of this technology was invented after you got your degree and you find the whole thing, with its cryptic terminology, very, very confusing. Or perhaps you are a plant manager with a bottlenecked plant or a plant with utility consumption, by your reckoning, excessive. You know that if you could hold that stoichiometric ratio steady, shift after shift, you could set records, but your conventional instrumentation just cannot deliver.

Whether you are a manager who wants just a brief exposure to the material, a person looking for ideas, or an engineer who needs a good grounding in the subject, there is material in this book for you. There are several ways to read it.

You may read it lightly, skipping any of the more difficult material. This will give you, if you are a manager, for example, a feel for the endeavor and some of its vocabulary. Or you may read it thoroughly. This will give a chemical engineer about to start his own project enough hindsight to make it successful. Or you may read it frequently to understand all of the material within the book, and then use that knowledge. Using that knowledge will turn your machines into bus bangers.

At the end of the book, the novice should have answered most of his questions, and the expert should have had some of his assumptions challenged. For both, the book contains material which should improve their results. In it is described the installation of a computer in a process—from proposal to total implementation.

This keeps the book practical, it allows for a better explanation of the alternatives, and it enables some of the ramifications of the actions taken to be explored. I immediately acknowledge that the way the project is handled in this book is not the only way the project could have been handled. But the approach I describe is easily followed, and it does produce results.

Most chemical engineers are acquainted with one or another attempt at computer control of a chemical process. Their overall perception is that it is extraordinarily difficult to get meaningful results—particularly results that will not deteriorate over time. Their perception is correct. But the prospective user can avoid many of the difficulties if at the beginning the project is approached correctly, and if he has a grasp of all the intricacies involved. It is hoped that the book will help him in both ways.

Always think of a project as consisting of four aspects, and view them as you would the four faces of a tetrahedron:

- 1. The electronic digital computer (the pieces of hardware themselves).
- 2. The operating system (the manufacturer-supplied software that makes the computer run).
- 3. The application software (written in the programming language of the user's choice).
- 4. The actual application (the use to which the other three are to be put).

Each bears on the other three; any one touches the other three; none can be chosen in a vacuum. Please bear this concept in mind throughout this book.

No specific manufacturer's machine will be detailed nor will any particular language be emphasized. Those readers who may be disheartened at this point may rest assured that the underlying principles are understood more easily and have a more universal application than any machine or language specifics. History has also been avoided. Historical circumstances and commercial convenience have obfuscated the "how" of what is a perfectly straightforward machine. If the software for the machine is considered as one giant algebraic expression and if the machine itself is considered as an automatic evaluator of that expression, then the interdependence of the two can be recognized. Furthermore, it should be realized that the expression is not the evaluation.

Three features of electronic digital computers must be mentioned so that all readers are aware of them. First, the computer will follow the program instructions in sequence automatically. Second, the program's instructions must be coded in numerical form for the machine to be able to use them. Finally, the machine does not handle numbers directly—it only handles registers, and it is these registers that contain the numbers. The elegant simplicity of these three features is what gives digital computers their power and universality. The simplicity is undiminished whatever the size or sophistication of the computer.

It is easy enough to recognize in a chemical process how a human-supervisory/human-controlled system works and what information it needs. Chemical engineers have at hand notebooks, handbooks, hand-held calculators, previously written algorithms and data tables, wall clocks, paper and pencil, appointment calendars, operating manuals, logbooks, foremen, and operators. With a knowledge of process tank gauges, material flows, pressures, and temperatures, the engineer can calculate optimum conditions for the plant equipment and the process. He can coordinate the production at the specified rate and initiate corrective action whenever deviations occur. This is done relatively slowly, but very visibly. The whole system is understood by all the people in contact with it.

In a computer-supervisory/computer-controlled system the workings and the needs are much more difficult to recognize. Indeed, there is a whole new terminology to learn. Such a system requires hardware and software. The hardware consists of the CPU, the memory, the hard disks, the floppy disks, the clocks, the communication interfaces, the video generators, the keyboards, the printers, the television monitors, the plant analog input interface device, the computer digital output interface device, and the paper-tape reader punch. The software consists of the system director program, the loading program, the start program, the patching program, the editing program, the math program, the input conversion program, the control program, the calculation program, the alarm-raising program, the CRT driver program, the teletypewriter driver program, the report-generating program, the data-gathering program, the plotting program, and a whole handful of datasets for data storage and display information purposes. Hidden in this software are the control algorithms that must be developed, the provisions that must be made to accommodate changing targets and limits, the handling of requests for displays and reports, and the flexibility needed as perceptions (as to how the process should be run) are modified. The flow of information from field measurement into the computer, and its storage and eventual regeneration back out of the computer onto paper or into video, is both fast and unseen. Few people in contact with the system understand its workings.

This book addresses these problems in the following ways:

Chapter I gives reasons as to why installing a computer is worth the effort required. It explores the software dilemma. It lists 16 questions to which answers must be found before any computerization project is initiated. A set of rules is given for handling the project. The chapter closes with some comments about programming productivity and program productivity.

Chapter 2 looks briefly at process instrumentation. Some chemical engineering fundamentals such as fluid flow measurement and fluid flow regulation are reviewed. The control of flow in pipes is studied at length. The conventional PID algorithm is examined.

Chapter 3 describes the Witches' Brew Process, the process that will be computerized in the course of this book. There is a process flow and instrument diagram. Inventories of equipment and instruments are included. The process's reaction and purification steps are described in detail. Balances on material and energy are given. Finally, the capital costs and process economics are included.

Chapter 4 looks at the hardware: memory, bulk storage, video display terminals, keyboards, paper-copy terminals, process input, process output, and information transmission. A system is configured.

Chapter 5 elucidates computer concepts and describes simple programming, floating-point math, and typical system software. A software inventory for the Witches' Brew Process is given. The iterative process of software generation is described thoroughly.

Chapter 6 returns to the Witches' Brew. The objectives of the project are outlined. The proposed computer system is inventoried and described, and the shopping lists are prepared. The chapter concludes with the economics of the proposal.

Chapter 7 examines the computerized Witches' Brew Process from process measurements through input, the mathematics, and output, to expected results. Several ways are suggested to generate data logging, conduct statistical studies, and plot optima.

Chapter 8 closes the control loops. It compares PID and non-PID algorithms, particularly decision trees. The deficiencies of analog controllers and the power of programmable processors are described. It explains what is involved in hierarchical control and total process control. The chapter ends with a comparison of diminishing returns, marginal returns, and most-effective returns.

Chapter 9 closes out the book with comments on yesterday and tomorrow. What lessons can we learn from the past? Where is the dizzying whirl of microelectronics taking us? Is there a nascent profession emerging? What software is available?

There are several underlying ideas presented in this book of which the reader should be aware.

First, the computer is a process-research aide of unimaginable skill. With a suitably designed data base, the graphing of two variables, the trending of a measurement, or the statistical analysis of a group of data are easily implemented. Any knowledge generated in this way gives an illuminating insight to the process. Using high-resolution plotters and theoretically sound statistical tests, it is no longer necessary to rely on conventional instrument paper charts or instinct to

distinguish the good from the bad. This means that the understanding, the progress, the value of the control strategies, and the techniques being implemented can be proven and documented. A process upset can be replayed in slow motion or stop frame. The process's inner happenings can be picked apart.

Second, making the digital computer a substitute for an analog controller with PID algorithm is not taking advantage of the machine's fullest capability. A correctly conceived computer-based process control effort will use the human operator's actions as a guide, not the workings of an analog-controller. As a consequence, there is no grand algorithm which can be universally implemented. Instead, what can be implemented are imaginative and sophisticated decision trees of unlimited variation that will handle both static and dynamic changes. Decisions within the tree are based on whether the deviation is correctable and worth correcting. How and where a valve must be positioned to reduce a deviation, to maximize an opportunity, or to improve the process are all considered in this book. It must be realized that a computer can handle not only many inputs simultaneously, but also several errors simultaneously. And, even more powerfully, the computer can handle process dead-time. That is worth repeating: the computer can handle process dead-time.

Third, the control valve is a variable restricting-orifice. It can be manipulated in any way that one sees fit. It can be slammed shut. It can be thrown wide open. It can be opened very, very slowly. It can be closed just a hair. It does not have to respond to every deviation. It can be positioned pre-emptively. It is a valid control strategy to hold the valve position rock-steady. It is an equally valid control strategy to jiggle the valve back and forth over a limited range.

Fourth, the effort of implementing computer control is subject to severe diminishing returns. It may take only 10% of the programming effort to give improved process control for 90% of the time. It may take nine times the original effort to make the computer give better process control than the next best alternative for the remaining 10% of the time. Computer control also produces great rewards. Perhaps raw material savings will pay for the installation and programming effort in five months. Perhaps a batch reactor's productivity will be doubled.

Fifth, computer operation and process control are very difficult to describe in the general case. But to refer to any one particular system makes for specifics that are of limited value. Consequently, this book describes an imaginary process and a virtual processor. Neither exists, in fact, but in general terms they are representative of a chemical process and a digital computer.

Sixth, there is a lot of confusion and ignorance concerning digital computers and process control. Some confuse "computer-the-CPU-chip" (which is impotent alone) with "computer-the-system" (a combination of software, hardware, and peripherals as powerful as your imagination will allow it to be). Some confuse "process control theory" (Nyquist diagrams, Laplace transforms, and PID algorithms) with "process control fact" (an experienced operator's ability to line-out an upset plant). No single book can address itself to helping everyone out of his

tar-pit, but it is hoped that this book will be a *first* step for some toward explaining the terms used, describing the operation of the equipment, and getting started in this field of endeavor.

At the end of this book you may not be able to tell a UART from an FPP, a T-state from a disk revolution. You still will not appreciate the merits of RATFOR versus FORTRAN IVH, or be able to distinguish a compiled BASIC from an integer BASIC—but you will be able to close a loop, understand the difference between DDC and SSC, and be able to configure a system that will meet *your* needs.

Last, flow control cannot be dismissed as simple. Temperature control, level control, and pressure control inevitably involve the control of fluid flow. Good flow control is THE fundamental building block to good process control.

NOTE: This book distinguishes between a computer cycle and a process period. A computer cycle is the periodicity of the computer's actions. The computer scans the chemical process, it calculates, it makes logical decisions, it makes adjustments, it updates various displays. It is then quiescent until this sequence of actions is repeated. That cycle of events is a computer cycle. It is measured in seconds.

A process period for a chemical process is that period of time that must elapse before any distinguishable change in a flow FROM the process is recognized following a change in some flow TO the process. It can also be taken to mean the time needed for any chemical or physical process to reach a stable equilibrium following a deliberate change of conditions. It is measured in minutes.

The slow progress and the disappointing results of computer control were mentioned earlier. Several reasons can be given:

#### 1. Oversimplification of the Problem

The digital control of a chemical process involves much more than the digitization of analog controllers. It requires a thorough examination and analysis of the process first. Not being able to calculate to six figures of significance does not limit the performance of analog controllers. Possibly the plant itself limits their performance.

#### 2. Overexaggeration of the Prowess of Computers

They are fast, they do not become bored, they are accurate to the limit of their means; but they are stupid, cannot think for themselves, and they must have everything letter-perfect.

#### 3. Misplaced Emphasis on the Latest Hardware

All equipment requires a learning curve. It is better to be high up on the learning curve of an "old" piece of electronic equipment that is reliable than it is to be

repeatedly on the low portions of curves of "new" and unreliable equipment. The human instinct to have the latest and the best is self-defeating.

#### 4. The Detraction of Supersophisticated Software

The temptation to race ahead and develop elegant solutions to resource sharing and problems of allocation, impressive displays of blinking colors and pulsing lines, and massive comprehensive management information systems—all this has been at the expense of understanding and strengthening the most basic assumptions about the processes and their control. Perhaps the foundations are wrong.

#### 5. Improper Resource Allocation

By far the biggest expense in any computerization project is lost opportunity cost: the dollar savings that are not being generated because the project is not complete. The second greatest expense is software development. The third greatest expense is the *process* interface. One of the smallest identifiable expenses is the CPU and its memory. Do not haggle for the cheapest CRT or cheapest CPU. Attention should be addressed to getting superfast equipment delivery, to identifying goals in software (a simple and quick approach), and finally to developing and installing better process interfaces.

#### 6. Use of the Wrong People

The common myth is that people with people-problems can work with machines where there is little people-involvement. They can become productive employees and yet not upset morale. *This is a disastrous error*. People implementing process automation by programmable processor should be superior to everyone else at human relations. They must persuade, educate, and train nearly everyone else who comes into contact with the machine. This includes craftsmen, instrument men, operators, engineers, managers, owners, and in some circumstances even vendors.

#### 7. Historical Circumstances

Engineers approach industrial chemistry after solving involved problems on large main-frame computers in the FORTRAN language using batch mode, and with programs and data entered on cards. Chemists approach industrial chemistry after organizing and supervising laboratory experiments with minimally configured mini-computers. The programs were entered in BASIC under time sharing, and data was read-in in real time. Neither approach is good preparation for process computers. The differences between the environments of a chemist in a lab, a person working on computer control of a process, and an engineer in a design office are listed in Tables I-1, I-2, and I-3. Each approaches the process computer

Table I-1
Approach: Chemist/Laboratory/Monitoring of Experiments/University

Purpose: To generate facts

Time Budget: Not critical, not time-limited

Dollar Budget: Severely restricted

Installation: Small data storage requirements (size of one experiment)

: Can halt machine at any time at user's convenience

: Non-automatic program loading acceptable : Cold starts inconvenient, but not a disaster

: Small communication interfaces (2 chan (a 110 baud)

: Small "front-end" (16 analog input; 16 DI/DO)

: Consequences of machine failure not severe

: Real-time system has some flexibility; batch possible

: Many applications of configuration

: Many applications of software, could be used elsewhere

: Math packages are involved, somewhat slow, and of great precision

: Machine's output itself is required result

: Affords people productivity (fewer required)

Environment: Infrequent people-turnover

: User very knowledgeable about computer system

: Unrestricted flows of user knowledge

: Labor intensive

: Very few users

: Non-team orientation

Overall: Cannot afford computer hardware; has time to develop software; chooses own hardware

## Table I-2 Approach: ?/Manufacturing/Control of Process Operation/Industry

Purpose: To produce chemicals Time Budget: Always insufficient

Dollar Budget: Elastic; capital available for good projects

Installation: Large on-line data storage requirements (many long histories)

: Machine must be "up" at all times

: Must have fully automatic program loading

: Ill afford system regeneration, too much history lost

: Medium communication interface (8 chan (a 2400 baud)

: Large "front-end" (320 analog input; 144 DI/DO)

: Machine failure very serious

: Very demanding real-time only

: Individual configuration unique

: Custom software, not usable elsewhere

: Math packages are simple, fast, and relatively accurate

: Required result comes from machine's output affecting real world

: Affords raw material productivity (more chemical)

Environment: Frequent people-turnover

: Users cannot afford to be ignorant of system

: User knowledge very restricted distribution, not easily passed on

: Capital intensive, people shy

: Many users, some trained, not all competent

: Orientation is to large teams

Overall: Can afford hardware; no time to develop software; chooses own hardware

Table I-3 Approach: Chemical Engineer/Office/Calculations/Commerce

Purpose: To design equipment

Time Budget: Comfortable Dollar Budget: Some constraint

Installation: Large off-line data storage requirements

: Machine can go down, some inconvenience to users

: Manual loading of programs from cards & tape acceptable

: System regeneration-minor inconvenience

: Large communication interface (32 chan (a 300 baud)

: No "front-end"

: Machine failure, an interruption only

: Time-sharing (of a forgiving nature) and batch

: Few of like configuration

: Packaged software; software re-usable elsewhere : Math packages complex and of sufficient accuracy

: Machine's output is required result

: Affords people productivity (more & better calculations)

Environment: Some people-turnover

: Users totally ignorant of computer system

: User knowledge has restricted distribution, but easily passed on

: Labor intensive (but not considered as such)

: Many users, all trained, most competent

: Orientation is to small teams

Overall: Hardware is not a consideration; software developed as necessary

differently. The engineer concentrates on sophisticated programs with little appreciation of the problems of real-time programming. He is tempted to buy packaged solutions to save time, and he has a predilection toward overly large, powerful systems. The chemist concentrates on undersized, inexpensive machines with straightforward programming and self-development of solutions.

With hindsight, it is easy to say that the best approach is down the middle, neither to one side nor the other. Avoid the system that is involved. It will be too difficult to get off the ground. Avoid the system that is too small. It will be outgrown quickly. What exemplifies the middle approach? That is still under active discussion by practitioners.

#### 8. Ingredients for Success

Although the computers themselves are mass-produced and inexpensive, inculcation of how to use them is still individualized and expensive. It is a practical learning experience (particularly so as the technical literature and documentation sometimes includes mistakes), is not usually self-explanatory, and does not always contain the greatest clarity of thought.

One cannot succeed without a high productivity in generating application software. High productivity comes from:

- 1. An operating knowledge of the peripherals (CRT, printer) as installed
- 2. A knowledge of the computer's "operating system"
- 3. A knowledge of the machine's EDIT and BATCH facilities
- 4. Fluency in the chosen language
- 5. Typing skills
- 6. The capability to flow chart logic diagrams
- 7. An understanding of the organization of the processor
- 8. An understanding of the communication protocols in use
- 9. And a machine with good UP-time

One cannot succeed without getting results from the application software. Good results stem from:

- 1. Good applications software
- 2. Knowing and understanding the process processor and all its peripherals
- 3. Knowing and understanding the process processor's "operating system"
- 4. Knowing and understanding the chemical process and plant
- 5. Knowledge, understanding, and creativity in process control

## CONTENTS

Preface
Introduction
Chapter 1 The Decision to Computerize
Chapter 2 Process Instrumentation and Control 14 Microcontrol. Conventional PID Algorithm.
Chapter 3 Case Study—The Witches' Brew Process .35 Process Summary. Equipment Inventory. Process and Instrumentation Description.
Chapter 4 Basic Computer Hardware 50  Binary Representation. Octal Representation. Hexadecimal Representation. Binary-Coded Decimal (BCD). Teletypewriter (TTW). Character Matrix. Local/Remote Operation. Full Duplex (FDX)/ Half Duplex (HDX). Control Instructions: Teletypewriter (plain). Control Instructions: Teletypewriter (fancy). ASCII (American Standard Code for Information Interchange). Serial Communications (EIA-RS232C/20mACL). Baud Rate. Parallel Communications. RS422. The Video Display Terminal. Video Graphics. RS-170. The Front-End. The System. The Arithetical Logical Unit (ALU). Configuring a System.

Chapter 5 Computer Programming, Operation, and Software
Chapter 6 Computerizing the Witches' Brew
<b>Process</b>
Chapter 7 Process Measurement, Mathematics, Data
Logging
Chapter 8 Closing Control Loops
Formulating the DRT Function. Flow, Control Valves, and Flow Control. Project: Close One Loop. Macrocontrol. Witches' Brew Computer Control.
Chapter 9 Conclusion—A Look Behind and Ahead
Appendix
Suggested Reading
Index