COMPUTER-AIDED PROCESS PLANT DESIGN

MICHAEL E. LEESLEY, Editor

- Elements of CAD systems
- System planning and evaluation
- Process design and project engineering
- Cases and applications

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Foreword

The importance of well-documented, careful design as a precursor to a successful process plant venture cannot be overstressed. Unless checked rigorously, errors accumulate throughout the design stages and cause delays in fabrication, erection, and start-up—delays which affect investment returns adversely. CAD techniques can help considerably.

First, the much greater calculation speed can be harnessed so that the long, tedious calculations necessary to analyze or simulate design can be carried out quickly and reliably. Second, data-storage hardware and database management software can be put to work to store design data so that it can be available instantly to engineers of all disciplines and be the means of producing uniform design documentation for fabricators, constructors, and erection personnel. Third, the ability to link graphics devices to a computer offers the designer every opportunity to compare the three-dimensional data model being built in the database with his mental picture of the design solution to the problem at hand. Also, such devices enable the production of a wide range of drawings and diagrams. Fourth, the ease of linking together many CAD and mainframe computers using advanced telecommunications means that the very best and most appropriate software can be brought to bear on a design problem in order to solve it in the most reliable way.

Yet in spite of these newly available techniques and capabilities, the market penetration of CAD in the process industries is still less than 3%. Perhaps this anomaly is caused by the conservative nature of the industry. This is unlikely since the productivity gains possible with CAD, especially in process design and piping, have been demonstrated to be at least 3:1 in favor of CAD methods. With an acute shortage of professional engineers, designers, and draftsmen, with process plant construction orders running around $150 billion a year, and with design activity currently costing the worldwide industry something like $30 billion a year, it is unlikely that that sheer conservatism alone is the reason for a slow acceptance of these new technologies. More likely, it is a suspicion of the new methods, brought about by lack of understanding of what the basic tools are, how they are used and the kind of impact possible in the various design offices which contribute to a completed plant design. This book is aimed at clarifying some of these issues and setting up, in the words of experts, an appreciation of CAD, its components, its use and likely impact, and its future. It is long overdue and I hope that its appearance on technical bookshelves will lead us to a future where process plant design is less costly and time-consuming than with conventional methods, a future where plants are easier and cheaper to construct and are safe, clean and highly productive.

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January 1982

Preface

As soon as computers were made reliable, their calculation speed was recognized and they became used for engineering design. At first, computer programs simply emulated traditional calculation methods. Manual design or analysis procedures were broken down into a series of single algorithmic steps and decision points, and the resulting list of arithmetic and logic instructions was coded line by line using one of the many programming languages available. The time and cost savings which ensued were most promising, and the phrase "computer-aided design" and its more common acronym, CAD, were coined.

After these early demonstrations of feasibility, CAD evolved quickly, in connection with a few major developments in computer science.

First, an increase in the size, power, and speed of computers led to the development and successful application of larger, more comprehensive programs and suites of programs to engineering problems of greater complexity. In addition, the powerful new computers made possible the evolution of operating systems allowing time sharing, in which many users could access the computer's power simultaneously using keyboard communication and high-level languages such as FORTRAN. No longer did an engineer need to be a computer expert to take advantage of the new tools.

Second, the development of data storage devices with reliable interfaces to computers enabled permanent data libraries of engineering components, physical properties, and cost data to be stored and accessed directly by design or analysis programs. Storage devices also made it possible to maintain project data (i.e. information about the specific project in hand) in a highly organized fashion.

Third, graphical input and output devices were linked directly to computer programs so that graphs and engineering drawings could be produced along with composite or tabular output.

Fourth, a means was found to link computers by high-speed telecommunications networks. This development led to distributed processing, where a specific task could be singled out of a project and allocated within a network to the computer most suited to that task.

As CAD evolves, design and analysis procedures are being examined and restructured into CAD techniques rather than into computerized manual methods. Further, as hardware and software integration has become feasible, total CAD systems have been emerging which not only carry out calculations but also contain routines for input, output, data management, component library searching, drafting, and modeling. Electronics, engineering, mechanical design, and drafting were the disciplines quickest to take advantage of CAD, and customized systems have now evolved offering productivity gains between 5:1 and 10:1.

Initially, process plant designers were more reluctant to try CAD except in flowsheeting and materials control. This was understandable: CAD is a three-dimensional, multidiscipline sequence which generates vast amounts of data and documentation. However, as the contributions in this book demonstrate, integrated CAD techniques are now being used successfully in almost all phases of process plant design. Assuming that further evolution occurs at least as rapidly as it has in other disciplines, we can expect in the next few years to see CAD systems capable of integrating and managing data for all aspects of process plant design.

This book is divided into five sections. The first discusses the basic items necessary to a CAD system. The authors have not attempted an advanced treatise on their topics, nor is that necessary for an understanding of the remaining sections.

The second section presents guidelines on how to introduce CAD into the design office and includes a detailed discussion of the importance of database management and how database technology can help with CAD of process plants. The third section takes this theme further by describing the likely impact in the contributing design offices.

The fourth section is the largest part of the book and shows the types of CAD systems available. Of course, this section could not and does not include all known experience. There were two criteria for selecting these contributions. First, it makes sense to write about systems which have been proven by repeated industrial application. Stringent application of this criterion eliminated many of the software packages which have been developed in universities. This led to the formulation of the second selection criterion, which was to include a description of systems which, although not yet used in industrial application, include special features or new techniques likely to be accepted and used in the near future. Some of the contributions describe systems which were deliberately written for use in a teaching environment. These are included to demonstrate that the basic CAD techniques are flexible enough to move from productive use to educational use of the software.

Since a great many systems in each design category meet these criteria, inclusion of all of them would have made section 4 hopelessly large and repetitive. I must here stress that although most of the systems in this section have proved their excellence, there are many more programs available which also meet these qualifications. I must also add that there is another reason why there are some obvious omissions: some of the invited authors declined to contribute.

The objective in compiling this section, then, was not to present an exhaustive survey of available software, but rather to give examples of what has been done.

There is now no question that CAD will become widely if not universally accepted and used, particularly as hardware costs fall steadily and software capabilities improve all the time. Justification and selection of CAD facilities must take into account the evolution of CAD, since it obviously affects current choices. With this in mind, the last section of the book contains two chapters by authors who have been closely concerned with CAD and who have attempted to extrapolate current needs into the future. Basing their judgment upon the CAD techniques currently available, they have attempted to foresee the path that CAD evolution will take.

In closing, I would like to draw attention and express my gratitude to a number of very important people who made this book possible. First, there are the many authors who contributed such fine papers. They have done an excellent job of setting down their experience in a way that can be readily understood by others. Second, I am grateful to the staff at Gulf Publishing Company, and in particular to B.J. Lowe whose encouragement was an essential ingredient to progress, and to Nancy Pierson who not only gave advice and guidance but also did a fine job of editing the final copy. Third, I am indebted to my wife, Barbara, for her encouragement and for the help she gave in retyping some of the papers and for assisting with the index.

Michael E. Leesley
January 1982

Contents

II System Planning and Evaluation

III Process Plant Design: The Impact of CAD

IV Specific CAD Developments

V Future Development

1

Central Processors

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For those who like to measure Man's progress in terms of ages and revolutions, we can surely be said to be in an electronics revolution and well on our way into the computer age. Progress is being made at an amazingly fast rate, and developments are having an increasing impact in the design office, the manufacturing plant, the executive suite, and more recently, in the home. Even engineers, normally among the first to understand and use new technology, can be left behind by the breakneck rate of improvements. This chapter attempts to supply sufficient background information on computers so that more-detailed discussions on various computer topics will be easily understood.

Also included are a historical perspective of the development of computers, some notes on modern computing technology, and a glimpse at what may develop in the future. Special emphasis has been placed on introducing terminology and concepts commonly used in discussions on computers and their applications.

A detailed description of each piece of hardware would be out of place here. Instead, the objectives have been to present an expanded glossary of terms and point to a bibliography.

Historical Aspects

In early attempts to record and calculate numbers, techniques like counting fingers or knots in ropes were used. Later, beads on strings were used—a technology which led to the invention of the abacus. Eventually, mechanical devices similar to clocks were developed which could perform simple mathematical operations. Some very large calculators of this type were built before they were superseded by modern computers in the late 1940s.

The mathematician Kelvin suggested using mechanical integrators to solve or analyze the mathematically more complex differential equations. Vannevar Bush, in 1931, published an article in *Journal of the Franklin Institution* which recounted the development of such a machine that could be programmed to help solve some complex mathematical equations. It was the first general-purpose machine of its type and was called a "differential analyzer."[1]

Differential analyzers received their peak use just before and during World War II. By the middle 1950s they were obsolete. In 1949, a digital version was invented, but even its reduced size did not allow it to compete with the new computers.[2]

Analog Computers

Differential analyzers are a special case of the more general analog computer. The trait which distinguishes analog from digital computers is that signals in the analog computer can assume any value between two limits—the values being determined by the magnitude of the signals. All computations necessary for solving an equation are carried out simultaneously. A separate set of electronics is required for each mathematical operation. If 20 additions are required, then 20 adders must be used. Also, different types of computational units are required for each type of operation (adders or integrators, for example). This method of operation limits the usefulness of analog computers in calculations involving many additions, subtractions, divisions, and multiplications. Analog computers are, however, useful for solving differential equations which have to be broken down by numerical methods for solution on digital computers. Hybrid computers, which use digital computers hooked up to analog computers, were developed to harness the best characteristics of both. Neither general-purpose analog computers nor hybrid computers are in widespread use today, and it is quite likely that their use will decline still more as digital computers and the means of programming them become more advanced. Special-purpose analog computers are still used in some areas such as process control.

Analog computers also work under very real accuracy limitations. The components can be made only so accurate, and increasing the accuracy is exorbitantly expensive—if possible at all. This limit is likely to be around 5–10 digits. A very effective solution to this is not to use infinitely variable values in the machine components but to encode all information as digital values using discrete voltage levels. Theoretically and in practice, any level of accuracy can be achieved by simply using more digits. This is the premise behind the design of digital computers.

Today the term "digital computer" refers to binary computers which depend on arithmetic with a base of two (therefore, two voltage levels). A single digit is represented internally as one of two discrete voltage levels: zero or unity.

Digital Computers

The first electronic computer, the ENIAC, was developed between 1943 and 1946.[3] It weighed 30 tons and filled a room 30 by 50 feet. The 18,000 vacuum tubes continually burned out and had to be replaced. Replacing them was a major part of the computer operation. The machine had no memory for programs, and so they were entered with plugged wires or "patching" cords.

A later electronic computer was the EDVAC. It was designed and constructed by the same group that made the ENIAC: the Moore School of Electrical Engineering at the University of Pennsylvania. EDVAC was installed at the Ballistic Research Labs at Aberdeen where it was operational by 1951. In 1952, the computer was available only 47.4 hours a week: it spent 104.8 hours in maintenance. By 1956, the computer ran 130 hours a week—still poor reliability by today's standards. The most important thing about the EDVAC was that it had the first memory (which used mercury delay lines) that could store programs.(4) Mercury delay lines used a column of mercury to store the electronic pulses as sound waves, which are much slower that the electronics. The sound waves were repeatedly read at one end of the mercury delay line and fed back into the other for as long as the signals needed to be remembered.

These machines and a few others are now referred to as first-generation digital computers. The second generation showed a marked improvement. These computers used transistors as their active elements and most were commercially viable. A number of different machines were on the market: the Stretch, LARC, Philco 2000, IBM 7090, RCA 301, and the CDC 160A.

Around 1964, a third generation began to appear. Most of these employed integrated circuit technology, but a few still used transistors. The major distinguishing feature was performance, which was greatly improved over second-generation machines.(5)

The primary concern of companies that produced early computers and, to a more balanced degree, the concern of modern designers, is the actual physical structure of the computer or hardware.

The modern computer is an integrated structure which comprises the hardware bus, the central processor unit and its arithmetic unit, and a memory. These are described individually in the following pages (except memory, which is the subject of Chapter 2).

The Hardware Bus

The hardware bus is the means of transmitting data from one part of the computer to another, and thus its design defines how data must be represented in a computer. Computers are binary, and a binary digit represents either a low- or high-state voltage. The mathematical symbols for the values are 0 and 1, respectively. A binary digit is commonly called a *bit,* and the number of bits necessary to represent one character is a *byte.* One or more bytes form a *word,* which is the basic unit with which computers work. The distinction between word and byte is often blurred and subject to special explanation. In general, the width of a word in bits is the width of the bus in wires.

Positive integers can be represented directly as binary numbers and stored as a word. The number of bits in a word (n) limits the largest positive integer to 2^n. For negative values, one extra bit is required to carry a negative sign. A number of different representations are used: signed magnitude, one's complement, and two's complement are the most common.

The most straightforward method is signed magnitude. One bit on the left of the byte is used to signify whether the number is positive or negative. In a)

$$57_{10} = 0{\times}2^7 + 0{\times}2^6 + 1{\times}2^5 + 1{\times}2^4 + 1{\times}2^3 + 0{\times}2^2 + 0{\times}2^1 + 1{\times}2^0$$

Polynomial expansion of base 10 number for conversion to base 2

b)	c)	d)
$57_{10} = 00111001_2$	$57_{10} = 00111001_2$	$-57_{10} = 11000110_2$
$-57_{10} = 10111001_2$	$-57_{10} = 11000110_2$	$+ \quad 1_2$
		11000111_2
signed magnitude	one's complement	two's complement

Figure 1-1. Representation of negative values in binary.

one's complement, each individual bit of the positive number is complemented, or negated, to produce a negative number of the same magnitude as the positive. Two's complement is the same as one's complement except that 1 is added to negative representations to get the two's complement equivalent. Examples are given in Figure 1-1.

Real numbers (i.e., values with a decimal part) are represented by floating-point numbers where both a mantissa and its exponent are stored in coded form in two separate words. Numbers of great magnitude and somewhat limited precision are storable with this technique. Like integer representations, the number of bits devoted to the mantissa determines the precision. If the mantissa can be allowed to occupy two words, the representation is said to be double precision.

Text and the alphabet are represented on a character-per-byte basis. Standard codes such as ASCII (seven-bit) or EBCIDIC (eight-bit) are commonly used. A word may be more than one character long: a Cyber 170 has 10 characters per word, for example. The left-hand bit of a byte is sometimes called the most significant bit, or MSB. The right hand is the least significant bit, or LSB. These terms are derived from the representation of numbers in binary where a bit to the left of another represents a higher power of two and, thus, greater value.

The simplest bus system for a computer has one bus connected to all the components of the computer. Only one word can be transferred anywhere within the computer at any given time. Several units might receive this word at the same time, but only one unit can ever put information onto the bus at any given time, since each wire can only carry one signal.

Multiple bus systems are more comman and much faster. An example is the Motorola M6800 microprocessor which has both a data bus and an address bus. (The data bus is 8 bits wide and the address bus is 16.) The two-bus arrangement allows several parts of an instruction to be executed at the same time, instead of the one-part-at-a-time method used by a single-bus machine.

The Central Processor Unit

The central processor unit (CPU) directs and controls the computer. It takes instructions and data from memory and sends out a stream of command signals to direct the computer. The CPU also performs the various calculations required