What Every Engineer Should Know / 10

WHAT EVERY ENGINEER SHOULD KNOW ABOUT

COMPUTER-AIDED DESIGN AND COMPUTER-AIDED MANUFACTURING

The CAD/CAM Revolution

John K. Krouse

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Preface

Computer-aided design (CAD) and computer-aided manufacturing (CAM) are affecting almost every area of engineering. The number of CAD/CAM installations is growing by more than 40% a year. By 1985, 90% of all mechanical drafting is expected to be done by CAD, and about 30% of all manufacturers probably will use some form of CAM.

Most experts agree that computer systems such as these will continue to do what they have always done: free engineers from the tedious, time-consuming tasks that have nothing to do with technical ingenuity. Experience shows that CAD/CAM speeds the engineering process, stripping away the drudgery and paper-work that inhibits productivity and creativity.

The National Science Foundation Center for Productivity states that "CAD/CAM has more potential to radically increase productivity than any development since electricity." And CAD/CAM is viewed by many as the key to improving manufacturing productivity and the best approach for overcoming the worldwide economic slump.

Even though CAD/CAM is a relatively new technology, it already is having a huge impact on engineering. Moreover, the capabilities and impact of future systems are sure to be even greater. Changes in engineering usually are slow and evolutionary. Even radical innovations usually cause no more than a ripple in engineering as a whole. But CAD/CAM is exploding in every corner of the profession like nothing before, and its effects are being felt in every phase of engineering. If there was ever anything in engineering that could be called a revolution, this is it.

CAD/CAM will magnify man's mental power just as the machines of the industrial revolution expanded the strength of his muscles. This wave of change, however, will depend not on exhaustible natural resources but on the limitless creativity of the human mind. And we are now just seeing the beginning of this new approach to engineering.

Engineers and managers trying to learn about this new technology often encounter obstacles. There is an abundance of literature on specific CAD/CAM systems and fragmented areas of computer technology. But not many well-rounded experts know how all the diverse areas fit together. And few can explain CAD/CAM in a vocabulary that novices can understand easily. In addition, there are fundamental problems in terminology and definition because CAD/CAM means different things to many people. Some regard CAD/CAM as automated drafting and NC tape preparation. Others include virtually all tasks performed with a computer as CAD/CAM. Engineers and managers clearly need explanations to put the picture into better focus.

The need for clarification is the inspiration for this book, which is intended to be a helpful guide to important activity in CAD/CAM. The book pinpoints and defines major CAD/CAM areas, shows how they fit together, describes major CAD/CAM users, and outlines the cooperative efforts to develop unified systems. The book is meant to serve as a solid base on which the novice may build further knowledge about CAD/CAM. And it may provide a revealing perspective of CAD/CAM even for those intimately involved with the technology.

John K. Krouse

About the Author

John K. Krouse is Staff Editor of *Machine Design Magazine.* He received the B.S. degree (1969) in physics from Case Institute of Technology, Cleveland, Ohio. Mr. Krouse's experience as an engineer involved designing control systems for guided missiles, torpedoes, and nuclear power systems at Vitro Laboratories, Gould Inc., and Bailey Controls Co. (1969–76). He currently specializes in CAD/CAM, and has published numerous articles on the subject. Mr. Krouse has won awards for editorial excellence from the American Society of Business Press Editors for his articles *Stress Analysis on a Budget* and *CAD/CAM: Bridging the Gap from Design to Production.*

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Birth and Growth of CAD/CAM

For a long time, computers were bulky, expensive machines that could be operated only by those familiar with programming and related tasks. But dramatic technical improvements have made them smaller, more powerful, less expensive, and much easier to use. As a result, computers have proliferated into many diverse areas and have transformed our world.

Business, education, medicine, science, and other sectors of our society have benefited from the computer. But the single area depending most on the computer and experiencing the most dramatic growth is CAD/CAM—the combined technology of computer-aided design (CAD) and computer-aided manufacturing (CAM). This skyrocketing technology is the result of years of development in which computer systems have continually evolved. Early work nearly forty years ago laid the foundation for today's CAD/CAM systems.

Digital computers first appeared in the 1940s. They were huge, electromechanical machines that used clicking relays to perform computations. The first and largest of this generation of computers was the 5-ton Automatic Sequence Controlled Calculator, or the MARK 1, shown in Figure 1.1. Electromechanical computers performed calculations much faster than earlier mechanical calculators and computers. The MARK 1, for example, could add or subtract two 23-digit numbers in 0.3 second. And it could multiply them in 6 seconds.

Soon relays and other mechanical moving parts were replaced by vacuum tubes. Electronic *flip-flop* circuits made of vacuum tubes were switched on and off like switches with electronic pulse signals. The first of these vacuum-tube computers was ENIAC (Electronic Numerical In-

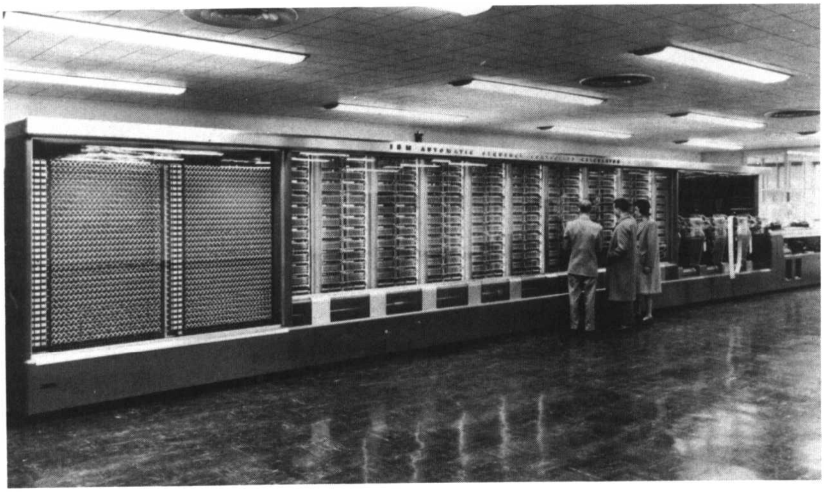

Figure 1.1. The first and largest electromechanical computer ever built was the MARK 1. Completed in 1944, the computer weighed 5 tons and contained over 3,300 relays connected by 500 miles of wiring. (Courtesy of IBM Corp., White Plains, New York.)

tegrator and Calculator) developed for the U.S. Army in 1946. Subsequently, many other vacuum-tube computers emerged in rapid succession in the late 1940s. One of the most powerful of these was IBM's Naval Ordnance Research Calculator shown in Figure 1.2.

Because the electronic pulses and circuits reacted thousands of times faster than mechanical parts, computation speed increased dramatically. In the mid-1940s, a vacuum-tube computer multiplied two 10-digit numbers in 1/40 second. By the mid-1950s, this was done in 1/2,000 second. Computing speed also increased with the advent of magnetic devices such as disks and drums for data storage, and magnetic cores for program memory. These replaced the punched cards and other manual data-entry methods of earlier computers.

Transistors replaced vacuum tubes in computer circuits in the late 1950s, creating a new generation of faster, more compact equipment. The most powerful computer of the day was IBM's STRETCH computer shown in Figure 1.3. The use of these solid-state devices changed computers dramatically. The transistor was 1/200 the size of a vacuum tube and could be packaged tightly because it produced only a fraction of the heat of vacuum tubes. Thus, computers became much more compact. Furthermore, signals had less distance to travel and response time of the solid-state devices was rapid; so computing speed also increased. Transistorized computers could multiply two 10-digit numbers in 1/100,000 second. In addition, solid-state transistors were far more rugged and reliable than vacuum tubes.

Computer size and cost were further reduced and computing speeds increased in the 1970s with integrated circuitry. Entire circuits consisting of thousands of transistors and other components were condensed onto confetti-size silicon chips. One of these chips from a computer-logic circuit is shown in Figure 1.4. The speed at which these chips switch signals permit the computer to make millions of calculations per second. It also reduces the size of the computer to a fraction of that normally required when circuits are made of discrete components.

Because of integrated circuit technology, computers today are much

Figure 1.2. The most powerful computer in the mid-1950s was the Naval Ordnance Research Calculator. It contained 9,000 vacuum tubes. (Courtesy of IBM Corp., White Plains, New York.)

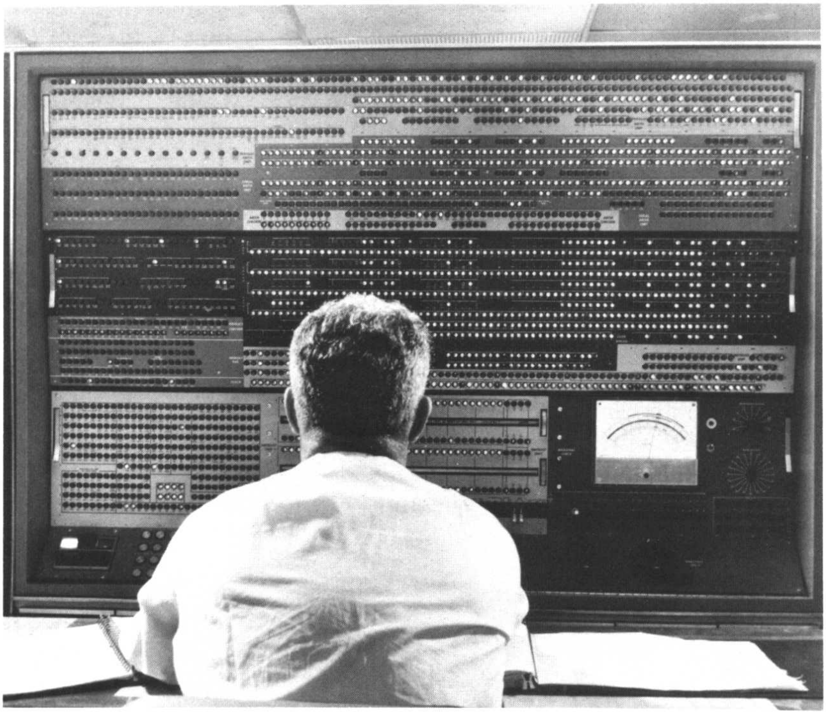

Figure 1.3. Built in 1960, the powerful STRETCH computer contained 150,000 transistors and could execute 100 billion instructions per day. (Courtesy of IBM Corp., White Plains, New York.)

more compact, faster, and less expensive than their earlier counterparts. The largest mainframe computers now manipulate huge amounts of data, and their power dwarfs that of earlier equipment. Furthermore, smaller minicomputers about the size of a desk now handle complex tasks such as stress analysis that only a few years ago required a mainframe. And typewriter-size desktop computers like the one in Figure 1.5 contain the computing power of a bulky system that would have filled a room years ago. The smallest is the so-called microcomputer that has all the necessary circuitry for elementary computations on a clipboard-sized printed-circuit board containing a few integrated circuit chips and other components. This dramatic compression of computer circuitry has given built-in intelligence to products such as ovens, tools, cash registers, and automobiles.

This entire range of computers—from giant mainframes to tiny microcomputers—are a part of CAD/CAM. Much of the equipment in a CAD/CAM system, such as intelligent terminals and plotters, have built-in microcomputers that assume some of the computing burden in the overall system and give peripheral equipment greater independent capabilities. Desktops are now being used with larger host computers for performing computations in sophisticated networks. Most turnkey systems that make up the greatest portion of CAD/CAM systems use minicomputers. And powerful mainframes perform structural analysis, manipulate huge matrices of data, and complete other complex tasks in the most sophisticated computer systems.

Researchers are still miniaturizing circuitry even further for faster, more compact computers of the future. Some experts even envision that analysis by the year 2000 may be performed on hand-held computing modules shown in Figure 1.6. These units are predicted to be so compact and economical that they will be used routinely by engineers much the same as pocket calculators are used today.

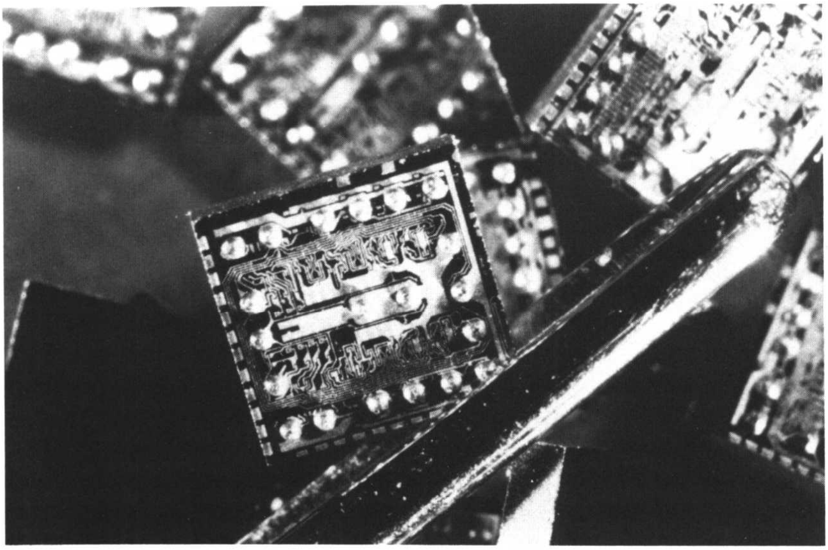

Figure 1.4. Contained in the eye of a needle, this silicon chip has miniaturized circuitry that switches a computer's electronic signals in a matter of nanoseconds. (Courtesy of IBM Corp., White Plains, New York.)

Figure 1.5. The IBM Model 5120 desktop computer has the power of equipment that 20 years ago filled a 20-by-30-foot room and weighed a ton. (Courtesy of IBM Corp., White Plains, New York.)

INTERACTIVE GRAPHICS

Computers are more compact, less expensive, and more powerful than ever. But one of the major reasons for the skyrocketing proliferation of CAD/CAM systems is the increasing ease with which a user communicates with the computer. Formerly, the user entered data and instructions into the computer with stacks of coded punched cards or reels of tape. And results were extracted from the computer in columns of raw numbers printed out on reams of perforated paper. Thus, the user had to be experienced in computer programming and operation to use the machine. And considerable time was usually required to execute a program and interpret the results.

But these early limitations of computer operation (which still prevail today in many people's minds when they think of a computer) were eliminated with the advent of interactive graphics. Here, the user communicates with the computer in display-screen pictures. Virtually no knowledge of computers is required to operate these so-called friendly systems. Furthermore, the communication between man and computer is carried out in real time. That is, the computer's response to its user's instructions is almost instantaneous.

An example of interactive computer graphics is shown in Figure 1.7. The terminal displays the results of a stress gradient analysis as lines of constant stress. Areas of high stress are easily pinpointed as those with high concentrations of the lines. The long list of numerical data which this

Figure 1.6. Future computer systems may be accessed through hand-held modules as compact and economical as today's pocket calculators. (Courtesy of Structural Dynamics Research Corp., Milford, Ohio.)

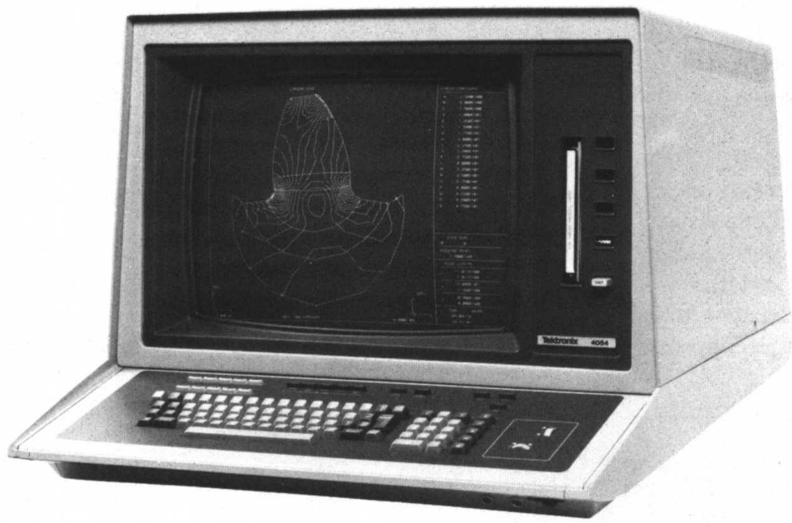

Figure 1.7. Concentration of stress lines easily pinpoints areas of potential fatigue in this plot displayed on a Tektronix Model 4054 interactive graphics terminal. The vast amount of data behind the plot would be tedious to interpret in tabular form. (Courtesy of Tektronix Inc., Beaverton, Oregon.)

plot represents would have been virtually indecipherable in tabular form.

Interactive graphics evolved as a means of conveniently translating man's mental images into computer language and vice versa. Internally, the computer handles its data in binary form. That is, all numbers, letters, symbols, and instructions are represented as a sequence of two digits—zeros and ones. A single letter of the alphabet, for example, might be represented by 11010001. This is called machine language.

Machine language is in binary form because of the ease with which the data can be manipulated in the computer. The zeros and ones of the machine language are simply represented by circuits in the computer being either off or on. In today's computers, compact integrated circuits are switched off and on. But the same basic principle was used to represent data in earlier computers with individual transistors, vacuum tubes, or electromechanical relays.

In the early days, a user communicated with the computer directly in machine language. That is, he wrote out long lists of zero-and-one sequences to execute even a simple command such as multiplication or division.

However, by the mid-1950s programming was simplified with symbolic coding. The programmer used a set of English-language statements that stood for certain standard computer commands. These statements were then converted automatically into machine language and fed into the computer by a translation program. One of the first high-level programming languages was FORTRAN (Formula Translation) developed for scientific and engineering data and still in wide use today. Other languages such as COBOL and BASIC for business applications also appeared and are still used.

These programming languages increased the speed with which a user could interact with the computer. But programming training skill at operating the computer and familiarity with the internal workings of the machine were generally required. And the lengthy numerical printouts containing the results from the computer were tedious and time-consuming to interpret.

Then in the early 1960s, interactive graphics was developed to permit a user to reap the benefits of the computer without training in programming, time-consuming coding, or other computer tasks. One of the earliest developments in interactive graphics was the Sketchpad Project at the Massachusetts Institute of Technology. In this system, a cathode-ray tube (CRT) display scope, similar to those used at that time to identify aircraft, was connected to a computer. Data was entered with a hand-held lightpen, which was a cylinder with a photocell attached to the end. The computer sensed the position of the lightpen on the scope and responded by lighting that point on the scope and storing the coordinate data in its memory.

By specifying points on the scope and executing simple computer commands, the user could quickly generate straight lines, circles, arcs, and other geometries. Producing a circle, for example, required the user only to specify the radius and the location of the center. With this technique, the user could quickly produce an entire diagram on the display screen. And the data base of coordinates stored in the computer could subsequently be used to manipulate the display image, produce hard-copy drawings, or be entered as an input to some form of geometric analysis. A feature that made interactive graphics so appealing was that the communication with the computer was carried on in real time. Thus, there was