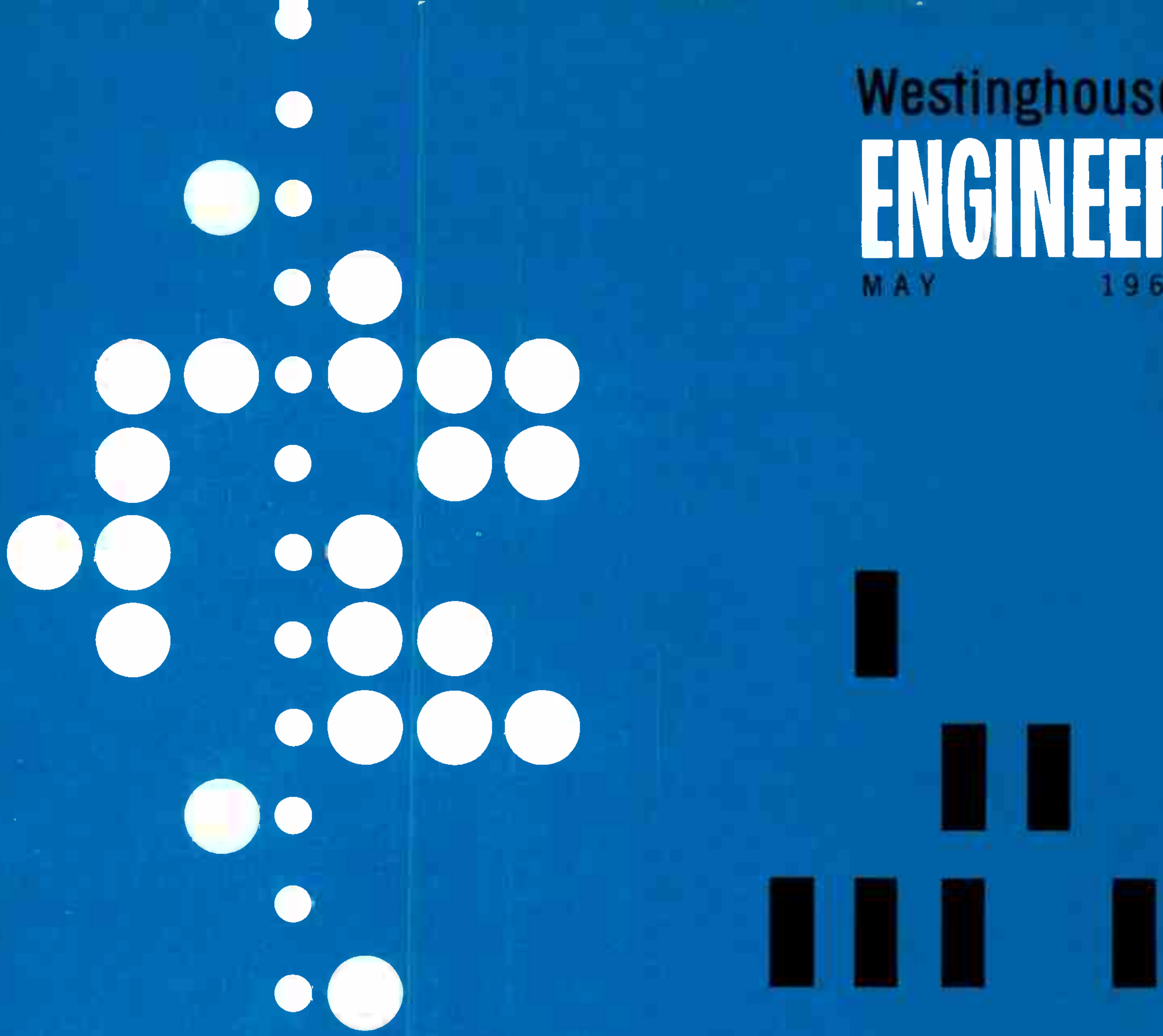
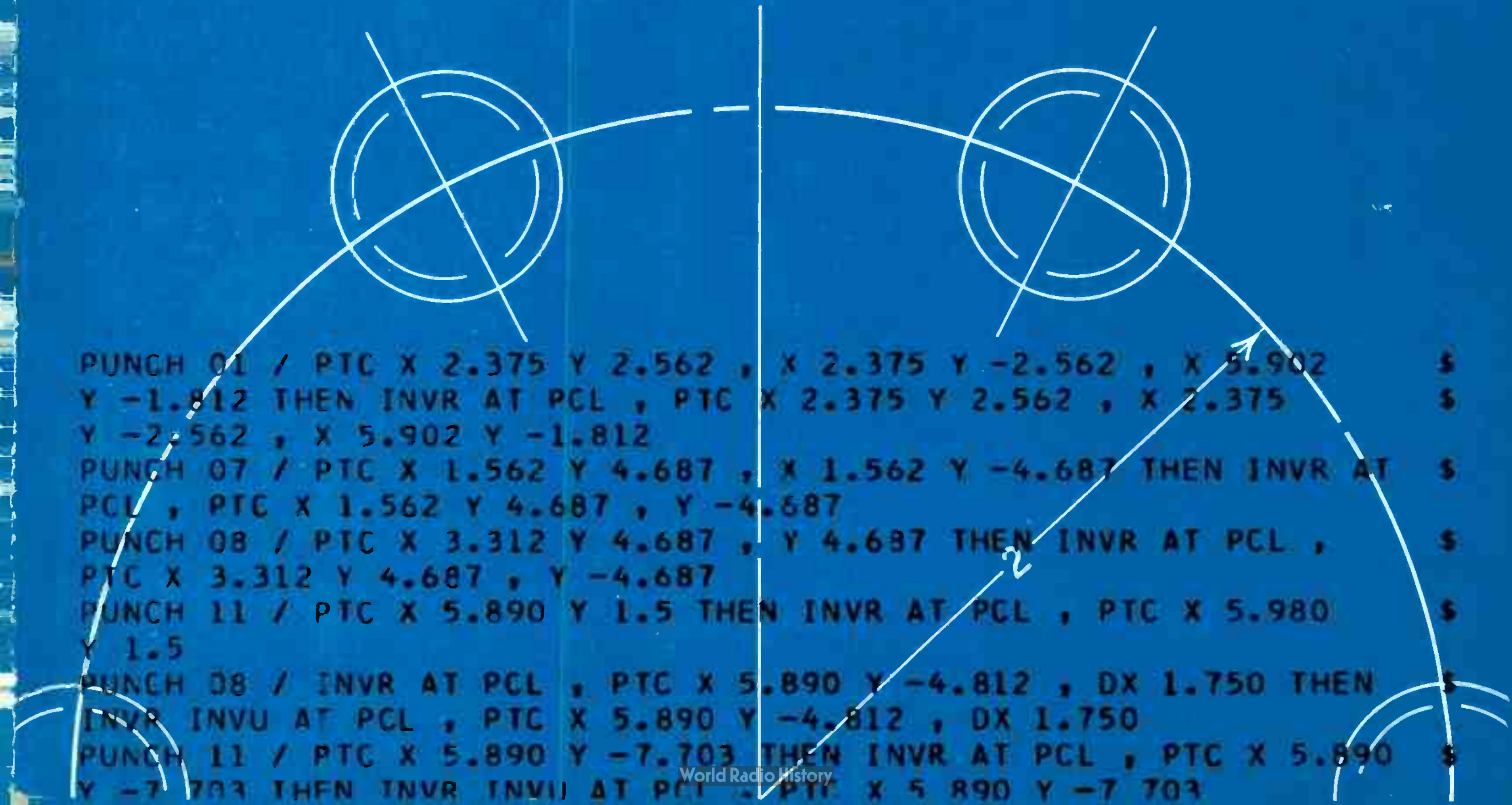
Westinghouse
ENGINEER

MAY 1963





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PUNCH 01 / PTC X 2.375 Y 2.562 , X 2.375 Y -2.562 , X 5.902      $
Y -1.812 THEN INVR AT PCL , PTC X 2.375 Y 2.562 , X 2.375        $
Y -2.562 , X 5.902 Y -1.812
PUNCH 07 / PTC X 1.562 Y 4.687 , X 1.562 Y -4.687 THEN INVR AT   $
PCL , PTC X 1.562 Y 4.687 , Y -4.687
PUNCH 08 / PTC X 3.312 Y 4.687 , Y 4.687 THEN INVR AT PCL ,      $
PTC X 3.312 Y 4.687 , Y -4.687
PUNCH 11 / PTC X 5.890 Y 1.5 THEN INVR AT PCL , PTC X 5.980      $
Y 1.5
PUNCH 08 / INVR AT PCL , PTC X 5.890 Y -4.812 , DX 1.750 THEN    $
INVR INVU AT PCL , PTC X 5.890 Y -4.812 , DX 1.750
PUNCH 11 / PTC X 5.890 Y -7.703 THEN INVR AT PCL , PTC X 5.890   $
Y -7.703 THEN INVR INVU AT PCL , PTC X 5.890 Y -7.703
```

Communications and the Engineer

Decision-making is a primary function of management today; and to make good decisions, management must have complete information. Because our technological pace continues to spiral, the *engineer* often has vital information needed in the making of critical decisions. But getting this technical information to management in a form that is helpful in decision-making is not easy; only good two-way communication channels throughout an entire organization can make this possible.

When the young engineer first comes into industry, he is primarily occupied with understanding his assignment and doing his limited job. He is probably using little initiative and is not in a position to sell new ideas. He is primarily on the "receiving end" of the communications channel. But as he grows, many opportunities for two-way communications arise—with fellow engineers, supervisors, and management. The situation becomes cumulative; good "receiving" helps build knowledge and understanding, and good "transmitting" is stimulating.

As the reservoir of knowledge fills, good two-way communications helps the engineer develop original ideas—technical, commercial, and managerial. But these ideas will soon die if he is unable to effectively communicate them. He loses both the stimulating effect of discussion and the incentive of having his ideas adopted. If not corrected, this situation can effectively shut off the supply to the reservoir.

As the engineer progresses, his horizon broadens and he no longer just produces as an individual—he becomes responsible for the production of others. Good communications are vital to good supervision—in assigning work and giving technical direction and assistance. The supervising engineer must spend much of his time planning, reporting, and selling ideas and programs to management. He also will have an increasing area of contact with his socio-political environment. Communications are essential to his continued progress.

The engineer must remember that his basic purpose is to alter the environment in which he exists—to reduce the probability that he is solely a target of external forces and increase the probability that he exerts force himself. He is of maximum value to his organization when he becomes an affecting agent. In this role, he must communicate to influence, to affect with intent. He must decide what response he is trying to obtain as a result of his communication. When he has learned to phrase his purposes in terms of specific desired responses, the engineer has taken the first step toward efficient and effective communication.

J W Simpson

J. W. SIMPSON
Vice President
Engineering and Research

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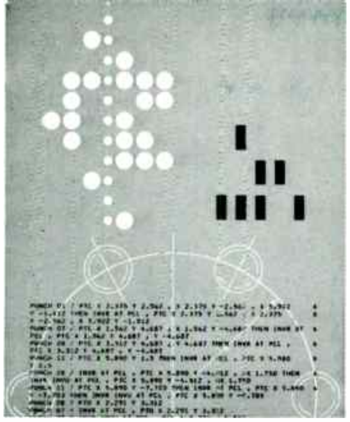
ENGINEER
MAY 1963



VOLUME 23 • NUMBER 3

Cover Design: Programming for numerical control is the subject of this month's cover. Designer Thomas Ruddy of Town Studios, Pittsburgh, has combined a mechanical drawing, a CAMP II manuscript, a punched card, and punched tape to suggest the translation of drawing information into machine instructions.

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Numerical Control 66
J. R. Jowett
Numerical control's flexibility fits it to the varied demands of modern manufacturing.

The CAMP II Numerical Control Programming System 70
D. C. Cumming and *C. M. Knarr*
A new computer-assisted programming method slashes programming cost and thereby increases numerical control's effectiveness.

A New Solar Telescope 76
Geo. F. Gayer
Scientists will get a better look at our closest star.

R & D: Low-Density Films and Electron Amplification 80
Improved electron multiplication is made possible by a film that is 98-percent nothing.

Programs for Power System Computing 82
E. L. Harder and *C. J. Baldwin*
A summary of the computer programs that are presently available for solving power system problems.

Bow Thruster Drives and Controls 87
J. L. Pinson
Motors for ships' bow thrusters can be sized economically by exploiting short-time overload capability.

Application of High-Voltage Power Fuses 90
Frank L. Cameron
Fuse selection should be the economic choice having the most desirable characteristics that will do the job.

Technology in Progress 94
Plasma-Jet Radiation Source Produces Intense Beam . . . Staged Power Modules for Reliable Inverter Service . . . Rolling Mill Designed for Lightweight Tinplate . . . Computer Method Determines Energy Requirements Accurately . . . Thermoelectric Space Power System Stores Solar Energy for Later Use . . . Largest All-Static Packaged Drive Operates Giant Cement Kiln. . . Products for Industry

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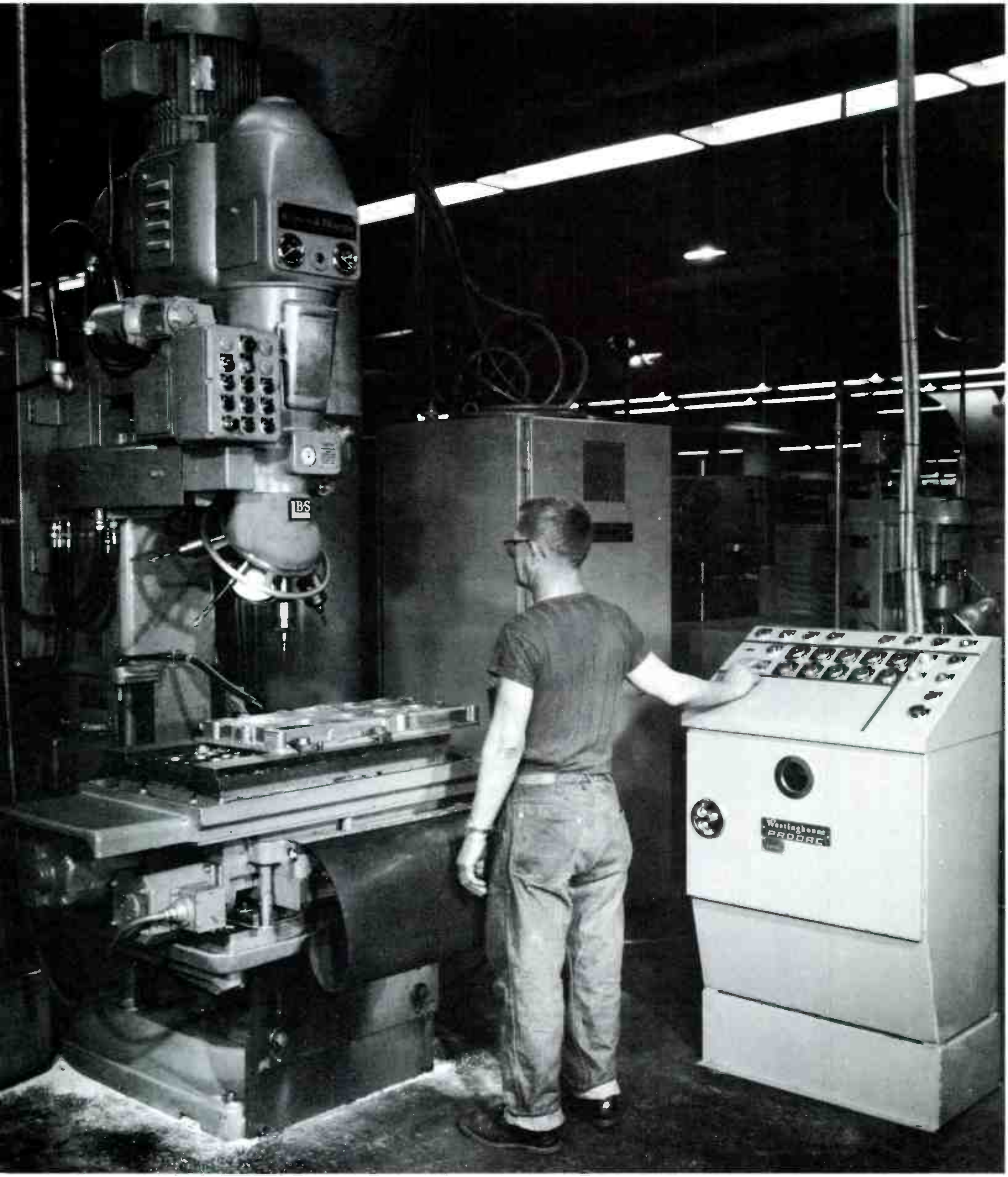

LBS
Westinghouse
PRODAC

Numerical Control

J. R. Jowett, Manager
Numerical Control Product Line Department
Systems Control Division
Westinghouse Electric Corporation
Buffalo, New York

The flexibility of numerical control systems makes them important tools for meeting the varied demands of modern manufacturing operations.

Numerical control is, essentially, the direct control of a system by conversion of numbers into physical values. The controlled system can be an individual machine or process or a group of machines or processes (or machines *and* processes).

A numerical control system receives instructions telling what machine motions are required and in what sequences they are required. The control portion of the system analyzes these instructions, interprets them, and coordinates the action of the drive portion of the system to cause the machine to go through the required motions or functions. The main building blocks that make up a typical numerical control system are shown, in the simplest form, in Fig. 1.

Information on what is required of the machine or process is entered into the control portion on punched cards or tape. A card or tape reader analyzes this information and passes it on to a brain center called the information processing logic. The information on the tape is in the form of numbers, so the information processing logic is generally digital circuitry composed of such components as transistor NOR elements, counters, delays, and arithmetic circuit elements. The circuitry is similar to that of digital computers.

The output of the information processing logic is generally of two kinds: information on various auxiliary functions the machine or process must perform (such as coolant on or off and spindle retract); and information as to where a machine member (a drill table, for example) is to go. The latter kind of output is the so-called "reference" to a servomechanism system. It can be in digital or analog form, depending on the requirements of the system.

Meanwhile, the machine member at this time is generally located in a position other than where the tape says it should be. The position transducer, a device located on the machine member, converts the position into a signal that the control system can perceive. Consequently, the system is being told two things: where the machine member should be, and where the machine member actually is.

An error detector circuit compares the position command with the actual position and produces a position error signal. Again, this position error signal can be either digital or analog, depending on the specific system. The error signal goes to an amplifier, which serves as a position regulator to activate the drive portion of the system and thereby move the machine member. The drive continues to activate the machine member as long as a position error comes from the "compare" portion of the system.

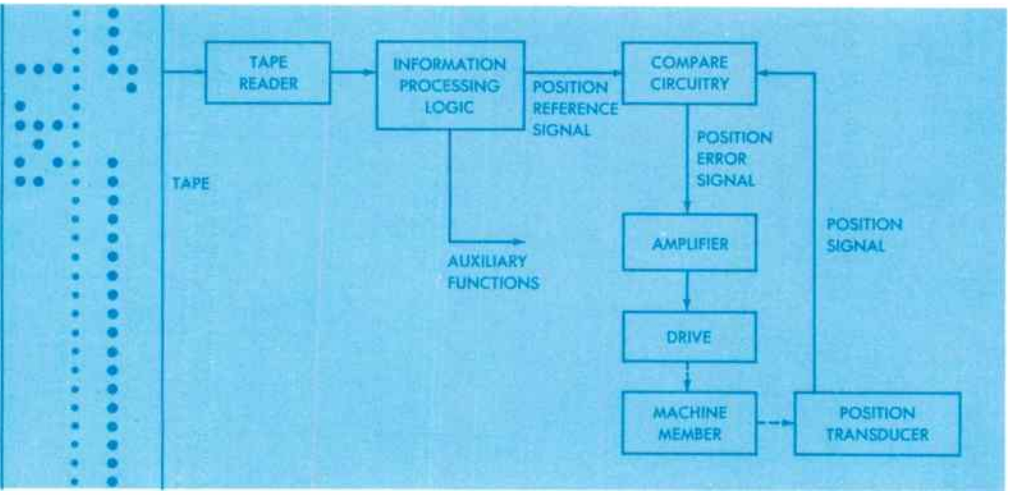
Instructions on tape have been used for some time to actuate simple systems, such as player pianos. However, the beginnings of actual numerical machine control occurred about 15 years ago with U. S. Air Force contracts for development of machine-tool controls. Results were encouraging, and in 1955 the Air Force ordered a number of numerically controlled machines. Most of these were in operation by 1957 as prototypes of the first generation of numerical control systems.

The market now is growing extremely rapidly, probably doubling every year. About 1500 numerical control units had been put into operation by the end of 1961; by the end of 1962, there were about 3000. Numerical control was an insignificant part of the total machine-tool business five years ago, but today it is used on close to 25 percent of all machine tools sold.

Use of numerical control probably will continue to expand, partly because of continued Air Force interest in it

Fig. 1 This block diagram illustrates the functional relationships of the main components of a numerical control system. Instructions on punched tape, and a signal of the position of a movable machine member, are used to generate an error signal that causes the machine member to go to the desired position.

Photo The worktable of this turret drill is positioned by a point-to-point numerical control system.



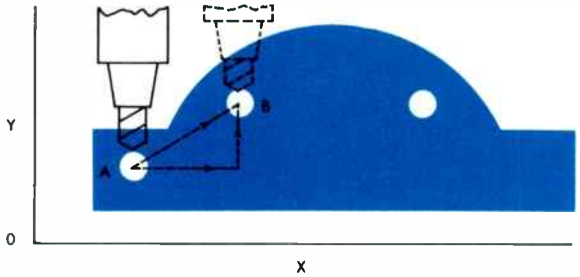


Fig. 2 Point-to-point control causes a machine member (here, a drill-press table) to move from one point to another in an *X* and *Y* coordinate system so that operations can be performed at the desired points. Any path of movement can be taken because the tool does no work during movement.

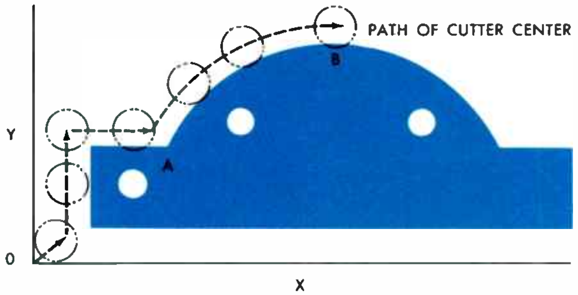
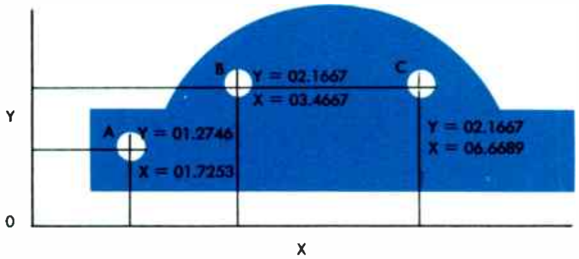


Fig. 3 Contouring control also causes a machine member (here, a milling cutter) to move in *X* and *Y* coordinates. The path taken is critical, because the tool cuts as it moves.



NUMERICAL CONTROL MANUSCRIPT

SEQUENCE	X	Y	SPEED	FEED	COOLANT
A	01.7253	01.2746	S4	F7	M08
B	03.4667	02.1667	S4	F7	M08
C	06.6689	02.1667	S4	F7	M08

Fig. 4 To program a tape for point-to-point control, work locations (holes, in this example) are defined on a part drawing with *X* and *Y* coordinates. The location information is typed in manuscript form along with information on the sequence of operations and drilling conditions required. The manuscript is then converted to punched tape by typing it on a tape-punching typewriter.

for production of aerospace components. Industry in general can be expected to turn to numerical control more and more as a means of reducing costs of manufacture. The future probably will see numerical control used in many applications other than machine tools.

Applications of Numerical Control

Numerical control systems fall into two general classifications—point-to-point and contouring.

In *point-to-point* control, the input instructs the machine member to move from one point to another with no concern about the path taken. For example, it could call for drilling a hole at point *A* and then one at point *B* (Fig. 2). The workpiece, in being moved from position *A* to position *B*, can follow any path because the tool is not doing any work.

In *contouring control*, also called continuous-path control, work is performed while the machine member moves from one point to another. Consequently, a predetermined path has to be followed. For example, the control might cause a tool to mill a contour from point *A* to point *B* along a path that approximates a parabola (Fig. 3).

It follows that point-to-point applications include drills, positioning tables, some turning machines, combination machines, and a few milling machines and jig borers. Most milling machines and many grinding machines have contouring control. Many of the combination machines have contouring capability built into them also.

More than 80 percent of the numerical control systems shipped so far have been of the point-to-point type. The numbers of industrial plants that have installed, and probably will install, numerically controlled machines are shown in the table.

The first numerically controlled drills were of the single spindle variety, in which a table was positioned under a single spindle in two motions or axes. Spindle speeds and feeds, and the tool to be used, were selected manually.

Turret drills were then introduced to increase flexibility. Initially, the two-axis table was positioned under a drill which was selected from six or eight choices in a turret. Spindle speeds and feeds and the depth the drill would go were still selected manually.

The next improvement was addition of a third axis control on the turret drill so the tape could call for the desired speeds, feeds, and depth of travel of the tool automatically.

The single-spindle drill controlled in two motions of the table and a third motion in the spindle has now been increased in capability by addition of an automatically controlled tool changer. The tape can select up to 30 tools of various kinds automatically.

Most of the functions programmed for the most flexible types of drill are also used on other machine tools.

Combination machines combine such functions as drilling, milling, boring, tapping, and turning. They range from fairly simple two-axis machines to machines with five or more axes. They may have point-to-point only, contouring only, or both point-to-point and contouring capability. These machines are increasing in popularity.

Turning machines with numerical control include most types of lathes, such as engine lathes and horizontal and vertical turret lathes. Many numerical control possibilities

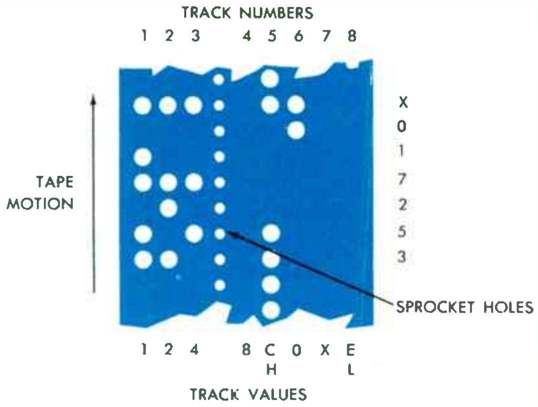
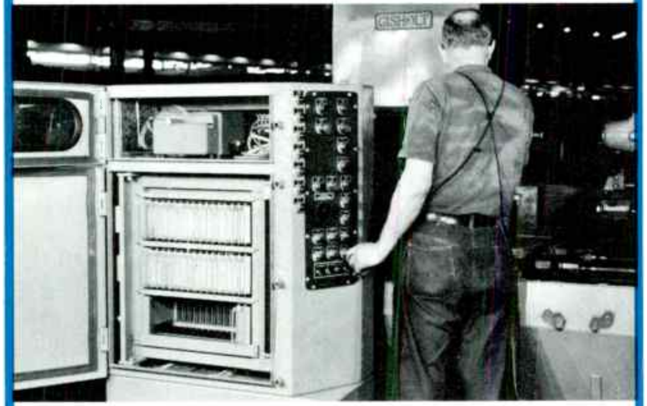


Fig. 5 This drawing of punched tape illustrates how the value $X = 01.7253$ is represented in the standard binary-coded decimal notation. The code representation of the letter "X" precedes the number. The numerals 1 through 9 are represented by holes in tracks 1, 2, 3, and 4. Track 5 is for parity check; an odd number of holes must appear across the tape when parity check is used. Tracks 6 and 7 are used for alphabetic and other special characters; a single hole in track 6 represents zero. Track 8 is used to indicate the end of a block of information (all the information that must be acted on at the same time).



This is the numerical control equipment for a turret lathe, with the cabinet door open. The tape reader is at the top, and below it are the plug-in modules that contain the digital circuitry of the information processing logic and other electronic components.

NUMBERS OF PLANTS WITH NUMERICALLY CONTROLLED MACHINES

Through 1962		1963 through 1965, Estimate	
Machine	Plants	Machine	Plants
Drills	1100	Drills	1100
Positioning Tables	500	Combination	1100
Turning	500	Positioning Tables	1100
Combination	450	Turning	800
Boring	400	Milling	800
Milling	350	Boring	500
Jig Boring	200	Jig Boring	400
Grinding	100	Grinding	300

remain to be exploited, especially in the simpler point-to-point controls for simple turret lathes.

The contour milling machine applications have been mainly in the aerospace industry. Jig boring also appears to be a specialty field; in many cases, a special type of numerical control system is needed to achieve the extreme accuracy and repeatability required. In grinding, numerical control has been applied mainly for special grinding of cams, rolls, and holes.

Punching machines have been developed primarily for sheet-metal fabrication so far, although applications have been developed for punching holes in structural steel members such as beams and plates. Opportunities in this field are many and varied.

While machine tools have presented the best opportunities for numerical control applications so far, other uses are developing. In the electronics industry, for example, many computer type circuits are being wired with numerically controlled wire-wrapping machines.

Automatic numerically controlled machines have been developed for inspection and quality control in production of intricate parts. Also, the shapes of many parts required in space-age industries are defined initially as complex mathematical formulas, and numerically controlled drafting machines can draw these shapes from the formulas.

Flame-cutting machines with numerical control are being applied, starting with the cutting out of large steel plates for shipbuilding. The Vikings in old Scandinavia can be said to have laid the groundwork for this application. They described the shapes of their wooden ships along X, Y, Z coordinates, so a Norwegian control manufacturer found it easy to talk to ship builders in terms they understood when applying numerical control.

Numerical control has also begun to prove its worth in transfer lines, welding, filament winding, and bulk handling and measuring of materials. Any operation that can be described in numbers and requires a high degree of process flexibility, or must permit a wide variation in product, is a candidate for numerical control.

The initial applications have been in single machines or processes, but, in the future, numerical control probably will involve coordinated control of a group of normally unassociated independent processes. This would result in numerically controlled manufacturing centers instead of the present individual numerically controlled tools.

Using Numerical Control

Point-to-point control is the simpler kind of numerical control to use. In machining operations, for example, a drawing of the part to be worked on is first given X and Y coordinates. If holes are to be drilled (Fig. 4), their locations are described in X and Y coordinates. The part programmer then prepares a manuscript, which is a sheet of paper that describes the machining sequences desired. It is generally typed on a special form prepared for the purpose and merely states (in this example) that, for each hole located at $X =$ something and $Y =$ something, certain conditions (such as speeds, feeds, coolants) are needed.

This information is then converted into a punched tape with a tape-punching typewriter. Reading the manuscript, the typist produces an instruction sheet; at the same time, a punched tape comes from the typewriter. The tape can be checked by "playing it back" on the typewriter to produce another typed instruction sheet for comparison with the original. Duplicate tapes also can be produced from the original tape. More complex manuscripts can be converted to tape efficiently with the Westinghouse CAMP II computer program. (*See The CAMP II Numerical Control Programming System*, below.)

The tape code has been standardized by the Electronic Industries Association. An example of punched-tape code is shown in Fig. 5.

Contouring programming is generally more complicated than point-to-point programming. However, it has been simplified a great deal by new generations of numerical control units that have built-in capability for producing certain curves automatically instead of having to go through the tedious task (either manually or by computer) of converting curves into simple straight-line motions.

Here again, the part programmer prepares a detailed manuscript from the drawing. The simpler manuscripts are then converted to tape with the special typewriter as in point-to-point programming. More complex manuscripts must be converted to tape with a computer program. Programs have been developed for various standard business computers; an example is the APT program used with the IBM 7090 or 7080 computer.

Either kind of numerical control produces the best results where imagination and flexibility exist. The personnel entrusted with the use of numerical control in a manufacturing center should be selected with this fact in mind. Occasionally, complete changes are needed in the way things are done, especially in manufacturing centers producing large numbers of parts on complex contouring machines. Generally, however, flexible attitudes among manufacturing and maintenance engineering personnel are all that is required for successful installations.

The amount of effort put into maintenance, and the degree of competence desired in the personnel who will keep the equipment running, depend on the value placed on down time. At one extreme, down time on a numerically controlled machine might close the plant. The best available man and equipment then is desirable. This man would be one whose talents in control system technology and manufacturing tools and techniques have been supplemented by specific training on the equipment. If down time is not expensive, maintenance service contracted to an outside firm or to the control supplier may be the answer. Usually, however, the minimum practical maintenance provision appears to be selection of a technician with both mechanical and electrical aptitude.

Justifying Numerical Control

Some economic evaluation studies have discouraged the initial installation of numerical control solely because the mathematics failed to justify the cost differential between

The CAMP II Numerical Control Programming System

A new computer-assisted method for preparing programs for point-to-point numerically controlled machine tools slashes programming cost and thereby increases the effectiveness of numerical control.

D. C. Cumming, Staff Assistant
C. M. Knarr, Engineer
Headquarters Manufacturing Planning
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Numerically controlled machines have consistently yielded impressive cost improvements in manufacturing. The main limitation on the usefulness of numerical control has been the fact that instructions for the machines have to be encoded in numbers and spelled out in meticulous detail with absolute accuracy. Manual programming, for anything but simple operations, is tedious, time-consuming, and subject to error. However, the new CAMP II programming system greatly increases the efficiency of the programming technique and thus is a potent source of additional manufacturing cost reduction.

The task of programming is both simplified and accelerated by using a computer to assist in preparing the numerical program for the machine tool. A computer makes lightning-fast error-free computations, and it can be programmed to comprehend instructions written in words as well as in numbers. To take advantage of these abilities, Westinghouse Headquarters Manufacturing Planning developed the CAMP II (Compiler for Automatic Machine Programming) system in cooperation with L. T. Krut of International Business Machines Corporation. The system, which will soon be generally available to industry, consists of two main elements: a flexible, general-purpose language and a program designed for an IBM 7090 computer. With this system, a parts programmer describes the part and writes the machining instructions in an English-like language that uses familiar shop terms. He feeds this information into the computer, which makes all the necessary calculations and translates the language into numerical terms that can be interpreted by the machine-tool controls.

The system accepts information and dimensions directly from the parts drawing. The programmer can reference instructions from any convenient point or line on the drawing, and he can locate all the parts dimensions in relation to the machine-tool coordinate system with only one statement.

Many style and size variations of the same type of part can be programmed with a master manuscript that generates all the different control tapes required. Moreover, a program can be adapted to produce tapes for new a manual and a numerically controlled tool. However, many of these evaluations failed to consider the fact that dollars represented by manufacturing time may be a poor yardstick. Manufacturing with numerical control generally means *changes in manufacturing techniques*, and not all of these changes are obvious or predictable. Simple economic evaluation of a prototype installation, therefore, fails to consider many factors.

Some symptoms that generally point to a need for considering numerical control are: Setup time is an appreciable percentage of total machining time; lead times are too long; tooling costs seem high; the part is too complex for an operator to make; human error is likely or is very expensive; increased capacity is needed.

In spite of the cost and relatively large amount of trouble with prototype units, with down times unusually high, many of the prototypes were economically justified. This is illustrated by the history of one of the first units Westinghouse built. It was decided to apply an early numerical control system to a turret drill on the basis of an original calculation of 25 percent return on the investment. The drill was expected to justify itself in quantities of from 5 to 50 pieces per lot run. It was believed that quantities of more than 50 pieces could best be produced on a conventional drill since the cost of tools, jigs, and fixtures would not be a major consideration in production of the larger quantities of pieces.

The expected problems arose, with both the machine and the control, during the first year. Although the operator had been prepared to expect these problems, he tended to prefer a conventional type of machine during this initial period. However, many unexpected benefits began to occur. Although the original estimate was for 25 percent return, better than 25 percent return was obtained on the basis of tool costs alone. Fewer tools were required, tool maintenance was lower, and, of course, far fewer jigs were required. Loading and unloading time was cut 50 percent. Most important was the reduction of lead time—the normal six-weeks time for the tool room to make fixtures was reduced to one week. Setup time was only a fifth of that for the conventional turret drill. Consequently, although it was originally believed that justification could be made in quantities of from 5 to 50 pieces, quantities as low as one or two actually were justified. On other pieces, the savings in cheaper jigs justified the running of more than 1000 pieces. Today, the operator complains loudly whenever this numerically controlled drill is down; he prefers it to conventional tools.

This case history is not only for a prototype control but also for the first numerical control installation in that particular user's plant. With the wealth of design and application experience accumulated since then, today's second and third generation control systems are certainly more likely to be justified.

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ENGINEER
May 1963

SAMPLE CAMP II MANUSCRIPT

```
          BEGIN 1
          REMARK / SAMPLE MANUSCRIPT FOR K+T MILWAUKEE-MATIC
          REMARK / PART IDENTIFICATION FOLLOWS
          PARTNO / SAMPLE BLOCK NO 1
          REMARK / TOOL INFORMATION FOLLOWS
          TOOL FACEMILL 0101 / D 2.625 EXT 4.004 FL 6 MTL 1 RH
          TOOL DRILL 2130 / D 1.5 EXT 7 FDR 5 MTL 0 RH
          TOOL BORE 0102 / D 2 EXT 6 FDR 7 MTL 0 RH
          TOOL ENDMILL 0106 / D 1.5 EXT 6 FL 6 MTL 0 RH
          TOOL DRILL 2010 / D .3125 EXT 6 FDR 7 MTL 0 RH
          TOOL TAP 3010 / D .375 EXT 7.5 THD 16 MTL 0 RH
          TOOL ENDMILL 0103 / FL 4 D 1 EXT 4.5 MTL 0 RH
          TOOL DRILL 0228 / FDR 10 EXT 6 D .25 MTL 0 RH
          REMARK / MATERIAL INFORMATION
          MATERIAL / RSF 2 HP .2 PFR .8
          REMARK / PART LOCATION
   ABLE=MODIFIER / ABS X 10 Y 9.5 Z 13 TP 2
  BAKER=MODIFIER / ABS X 10 Y 9.5 Z 10 TP 6
          REMARK / MACHINING INSTRUCTIONS
          START / ABS ( 0,0,0 ) TP 2
          FACEMILL 0101 / ABLE X -3 Y -3 Z .125 RTO DX 6 UTO DY 6 DP .125
          DRILL 2130 / ABLE DP 2.5
          CBORE 0102 / ABLE DP .437
          ENDMILL 0106 / ARC CTR AT ABLE , R 2.5 A 0 CCTO A 360 TLLF DP .187
  PATT1=POINT / CIRCLE PATTERN CTR AT ABLE , R 1.75 A 0 CCTO N 6 Z-.187
          DRILL 2010 / PATT1 DP .625
          TAP 3010 / PATT1 DP .5
          POCKMILL 0103 / BAKER X -1.375 Y -2.5 UTO DY 5 RTO DX 2.75 DP .5
          ENDMILL 0103 / BAKER X -3.625 RTO X -.875 DP .125
  CHUCK=POINT / BAKER X -.8125
          ENDMILL 0103 / SLO CHUCK X 1.5 A 30 RTO X 4.25 DP .125
          ENDMILL 0103 / SLO CHUCK X 1.5 A -30 RTO X 4.25 DP .125
  PATT2=POINT / PATTERN X 3  Z -.125 , X 3.875
          DRILL 0228 / ROTATE -30 AT CHUCK , CHUCK PATT2 DP .5
          DRILL 0228 / ROTATE 30 AT CHUCK , CHUCK PATT2 DP .5
          DRILL 0228 / BAKER X -1.75 Z -.125 DP .5 THEN DX -.875
          STOP / ABS ( 0,0,0 ) TP 4
          REMARK / END OF MACHINING INSTRUCTIONS
          FINI
          EOF
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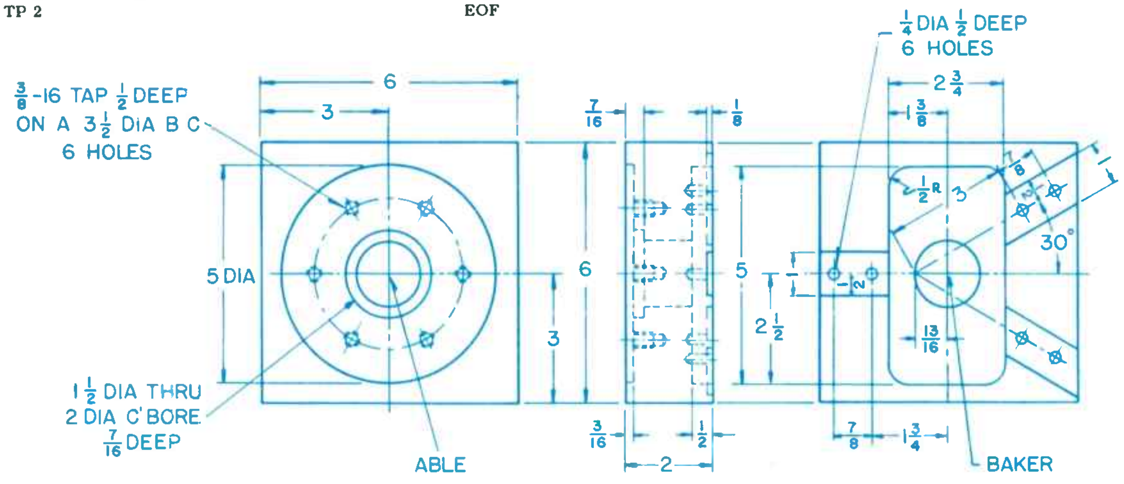


types of machine tools in about one-fifth the time formerly required. These capabilities can cut programming cost for any part by a factor of five or more.

Development of CAMP II

Westinghouse undertook the CAMP I project in 1958 as a pilot effort to determine the feasibility of using a computer to produce control tapes for a Kearney & Trecker Milwaukee-matic multipurpose machine tool. It had been generally recognized that machining most contour parts with numerical control methods would not be economically feasible if it were necessary to use manual programming procedures. It was not so clear, though, that using a computer was justified to assist in producing control tapes for the much simpler (in general) point-to-point machine tools.

The CAMP I system produced a four-to-one cost reduction per final control tape for this specific machine tool. Its major drawback was that it used a positional type of language and had no symbolic capabilities; that is, all instructions had to be explicit and had to be entered in numbers.

The CAMP II programming system was then designed on the basis of the following conclusions drawn from the CAMP I project:

1) The largest problem facing numerical control programmers is the reconciling of drawing-room dimensioning conventions and machine-tool coordinate systems. The machine tool needs all dimensions stated in terms of its coordinates. However, the dimensions required by the machine tool and those on the engineering drawing may differ in coordinate origin or form; e.g., one may have rectangular and the other polar coordinates. Much of the programmer's effort is in converting one set of numerical values to another.

2) Any machine operation requires a series of steps to produce the desired result. Therefore, a manual programmer has to supply repetitively the expansion of movements required to perform even simple operations.

3) Many drawings are dimensioned symbolically to cover a range of part sizes, so a programming language should be symbolic in structure. With such a language, a part can be symbolically defined and then all the control tapes required for the various sizes can be produced from a master manuscript in one pass through the system. This symbolic language structure is the biggest advantage of the CAMP II system.

4) Because of the tremendous amount of detail accuracy required, a sizable reduction in rework time and effort can be realized by mechanizing the error-prone areas of programming and tape production.

5) Although the language of drawing and machining is common and well defined, numerical control languages differ widely; a computer system can do much to close the gap.

In brief, the CAMP II system was developed to provide the numerical control programmer with a language that is drawing oriented in dimensional phraseology and machining oriented in operation phraseology. The programmer need only specify operations and the locations at which the operations are to occur. The system then automatically generates the sequence of control instructions, in accordance with accepted machining conventions, needed to perform each of these operations and to reposition the tool as required.

Programming with the CAMP II System

The programmer defines points on the drawing in terms of other points and in terms of the part's location on the machine tool. With the reference structure of centerpoint locations on the part defined, the programmer next writes statements that define locations and specify operations. He combines these statements to form a manuscript that lists all the operations to be performed on the part. (See *Sample CAMP II Manuscript*, p. 71.)

CAMP II statements are composed of two sections; the major section describing the operation and selecting the tool to be used, and the minor section describing the location of the operation on the part and any auxiliary information required (such as depth of cut, feed, and speed). The statements are written in simple English-like words and are easy to construct and read.

The CAMP II language consists of 120 commands and variables that can be arranged to cover a great range of programming situations. In addition to this standard vocabulary, up to 10 auxiliary commands may be added for any machine tool. In general, the language has the necessary capabilities to handle all point-to-point operations. It also can handle connected-path and pocket-milling operations to a limited degree. No attempt is made to fully control motions, since this capability is in most cases beyond the limits of a point-to-point system.

The CAMP II system has been designed to accommodate as many as 30 different machine-tool control configurations on one computer. The tools that can be controlled range from the simple two-axis to much more complex four- and five-axis machine tools.

Single-Position Operations—With CAMP II, the programmer describes the relationship of the part to the machine tool by writing a simple modifier statement that describes a single reference point on the part in terms of the machine tool's coordinate system. The first statement in Fig. 1 is an example of a Kearney & Trecker Milwaukee-matic modifier statement.

The first word (POINTA, in this example) symbolically labels the information to follow so that it can be referred to later. The choice of this word is left to the programmer; it can be any word up to six characters in length and not a word in the CAMP II language. The word MODIFIER indicates that the function of this statement is to define a part with respect to a machine reference point. All information after the / constitutes the minor section; it must be in terms of the machine-tool coordinate system and must include all information necessary to the description of a point. In this example, it includes the absolute (ABS) coordinate values of X, Y, Z and the table position. Once a reference point has been defined, all coordinate departures from the point are described in standard Electronic Industry Association terms.

A command to drill a hole is illustrated by the second statement in Fig. 1. The command DRILL provides the operation description; that is, it tells the computer to generate a series of instructions or movements necessary to drill a hole. The tool number (0101) supplies tool information, previously defined in terms of feed, speed, and tool extension. The information after the / defines the location at which the hole is to be drilled (POINTA) and the depth (DP 1) of the hole. The location of POINTA has previously been defined in terms of its location on the machine tool; it could also have been defined in terms of its location with respect to another reference point on the part.

Several things should be noted in the previous example. First, the statement is operational—it speaks of drilling a hole with a certain tool. Second, the coordinate information and depth information are taken directly from drawing dimensions, eliminating conversion from one coordinate system to another. The coordinate system of the drawing (that is, the center-line locations on the drawing) can be written in terms of their drawing dimensions and stored in the computer to be referred to at any time.

CAMP II statements can be written with rectangular coordinates, polar coordinates, or a combination of the two. Coordinate systems can be rotated off the machine-tool axis for flexibility in using dimensions directly from the drawing. An example of this ability is shown in Fig. 2. The statement reads, "Drill with tool 0101 at a location of 1.5 inches in the X direction and 0.5 inch in the Y direction from reference point PTA to a depth of 1 inch. Then drill another hole at a radius of 1.875 inch and at an angle of 60 degrees from PTA to a depth of 1 inch." The reference point and depth are not specified for the second hole because they were not changed.

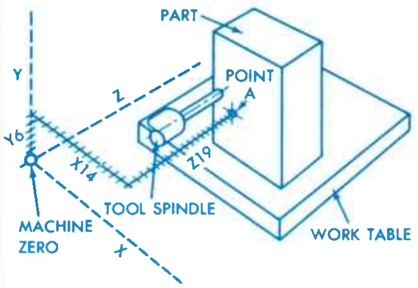
Besides flexibility in handling coordinates, the CAMP II system offers economies in programming common patterns of points whose relationship can be mathematically defined (such as lines of point locations or circles of points). A line of holes, for example, could be programmed with the first statement shown in Fig. 3. The minor section defines a line pattern of points starting at PTB and going right (RTO) at a distance of 1 inch between points (DX 1) for a total of five points (N 5).

Similarly, a circle of points could be programmed with the second statement in Fig. 3. The minor section of this statement defines a circle pattern of points whose center is at PTD and whose first point is at a radius of 3 inches and an angle of 0 degrees, going counterclockwise with the circle divided into eight parts.

Such groups of points, line patterns, and circle patterns, randomly spaced but requiring similar operations, are often encountered. The CAMP II system allows these common groups to be specified in a single machining statement. It also permits specifying groups of locations in terms of other groups of locations.

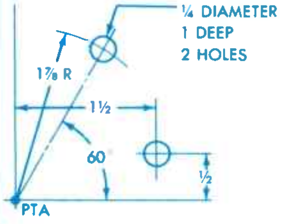
Milling Operations—Although most operations on point-to-point machine tools take place at a single coordinate value, many point-to-point tools have limited milling capabilities. To accommodate this class of operation, the CAMP II language can direct straight-line, slope-line, and arc milling operations. Lines and arcs can be specified as a series of connected paths as shown in Fig. 4.

The statement in Fig. 4 reads, "Endmill with tool number 0104 on a slope (SLO), starting at Peter, right to a radius of 2 inches and an angle of 20 degrees to a depth of 0.25 inch. Continue on an arc whose center is at Paul and whose starting point is at a radius of 1.5 inch and an angle of 110 degrees from Paul clockwise to an incremental



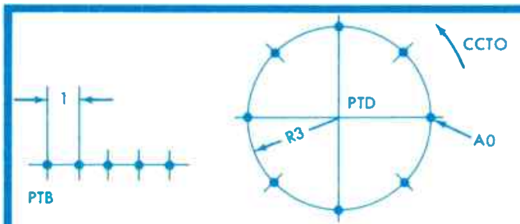
```
POINTA = MODIFIER / ABS X 14 Y 6 Z 19 TP0
         DRILL 0101 / POINTA DP 1
```

Fig. 1 An advantage of the CAMP II language is that it permits symbolic labeling of reference points. In this example, the first statement labels POINTA by defining it with respect to a machine reference point. The second statement defines the drilling operation to be performed at that point. Statements are written in a simple English-like language.



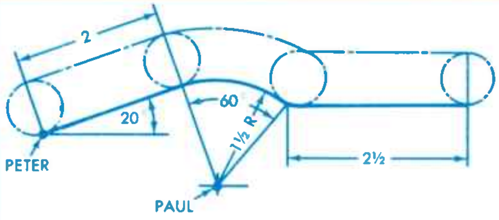
```
DRILL 0101 / PTA X 1.5 Y .5 DP 1 THEN R 1.875 A 60
```

Fig. 2 CAMP II statements can be written with both rectangular and polar coordinates. The lower hole here is located with respect to the reference point with rectangular coordinates, and the upper one is located with respect to the reference point by specifying radius and angle.



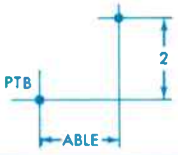
```
DRILL 0101 / LINE PATTERN PTB RTO DX 1 N 5 DP 1
DRILL 0101 / CIRCLE PATTERN CTR AT PTD , R 3 A 0 CCTO N 8 DP 1
```

Fig. 3 Patterns of points can be programmed economically as illustrated here. The first statement defines a line of holes; the second, a circle of holes.



```
ENDMILL 0104 / SLO AT PETER RTO R 2 A 20 DP .25 ARC $
        CTR AT  PAUL , R 1.5 A 110 CTO DA 60 RTO DX 2.5 TLLF
```

Fig. 4 The CAMP II system is primarily for programming point-to-point operations, but it also has contouring capabilities. This statement directs slope-line, arc, and straight-line milling cuts. (The $ indicates that the statement continues to another line.)



PART	ABLE
1	5
2	6
3	5.5

Fig. 5 Symbolic dimensions (ABLE in this example) permit one drawing to serve for a number of parts. Such symbolic dimensions can be defined in statements, labeled, and later recalled by the computer when the label is referred to.

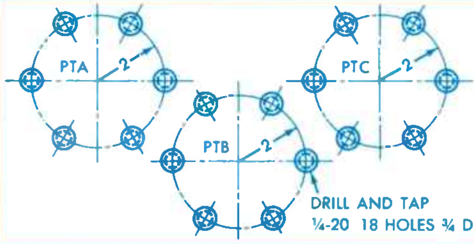
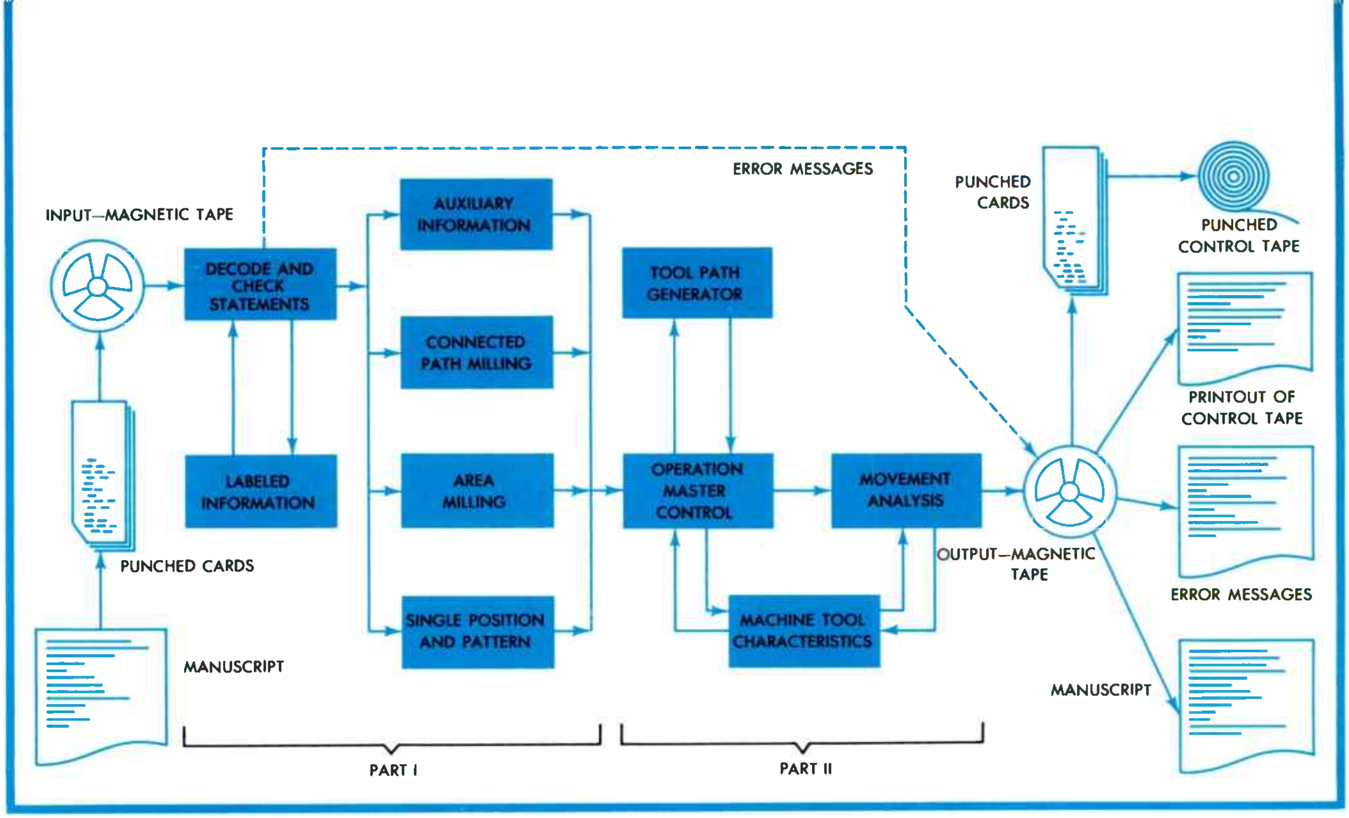


Fig. 6 Common groups of operations are often encountered at different locations. The programmer writes statements to define the set of operations and then writes a DO statement to repeat this set of operations at the different locations.



angle (DA) of 60 degrees. Then right to an increment in X (DX) of 2.5 inches with the tool to the left (TLLF) of the line."

Another class of milling operation is the removal of metal from a rectangular area by directing the tool through a series of movements to cover the area. A typical statement would be: FACEMILL 0102 / PAUL UTO PETER RTO HENRY DP .25.

This statement reads, "Facemill with tool number 0102 a rectangular area, with one side starting at point Paul up to a second point Peter and an adjoining side starting from Peter right to Henry, to a depth of 0.25 inch." The rectangular area to be covered is described by three points. The first and second points (Paul and Peter) define one side of the rectangle and the second and third points (Peter and Henry) an adjoining side. The tool moves along the first side and then the second, spiraling inward until the area is machined. The programmer, by his choice of corner points, can control the tool movements and whether the spiral is in a clockwise or counterclockwise direction. The tool in the example starts outside the area and covers the entire area; other operational commands can make the tool stay inside one side or inside the area entirely.

Symbolic Dimensioning—Many drawings employ symbolic dimensions to give the drawing a range of application over many parts. Also, many common details on drawings are identical except for their location on the part. The CAMP II system accepts dimensions that are symbolically defined, and this allows the programmer to write general manuscripts having wide application. Dimensions, groups of dimensions, operations, and groups of operations can be defined by tagging them with a label and later recalled by referring to the label.

An example of a symbolic dimension (ABLE) is shown in Fig. 5. The programmer labels a group of operations for later recall and execution with DEFINE and END statements. Thus, a manuscript for the operation illustrated in Fig. 5 would be:

```
DEFINE PROGA
START / PTB
DRILL 0101 / PTB X ABLE Y 2 DP 1
STOP / PTB
END PROGA.
```

A program tape for the machine-tool control can then be produced by defining ABLE and recalling the group of statements with a DO statement (DO PROGA). The three tapes required for the preceding example would be produced with the following statements:

```
   PARTNO / PART 1
ABLE = / X 5
   DO PROGA
   PARTNO / PART 2
ABLE = / X 6
   DO PROGA
   PARTNO / PART 3
ABLE = / X 5.5
   DO PROGA.
```

A different application of the DO statement, that of locating common groups of operations at different points on the part, is shown in Fig. 6. The set of operations is defined as follows:

```
         DEFINE BCIRC1
PATT1 =  POINT / CIRCLE PATTERN CTR AT (0, 0, 0) R 2
           A 0 CCTO N 6
         SPDRL 0101 / PATT1 DP .125
         DRILL 0102 / PATT1 DP .875
         TAP 3003 / PATT1 DP .75
         END BCIRC1.
```

A DO statement then repeats the defined set of operations at the three locations, PTA, PTB, and PTC:

```
   DO BCIRC1 / PATTERN PTA, PTB, PTC CYCLE or
   DO BCIRC1 / PATTERN PTA, PTB, PTC SEQ.
```

Fig. 7 The CAMP II computer system for programming machine tools consists of two main parts. Part I decodes and checks input information and directs it to Part II through the appropriate operation channels. Part II draws on this information and on stored information concerning the machine tool to determine the tool movements needed to perform the desired operations. Its output becomes a punched tape that is used to control the machine tool.

The DO statement can be programmed in either CYCLE or SEQ mode. In cycle mode, all the operations in the defined program (spotdrill, drill, and tap) are done at the first location before proceeding to the second location and so on. In sequence mode, each statement in the defined program is done at all locations in the DO statement before proceeding to the next statement in the program.

Feed and Speed Calculation—If a machine can change feeds and speeds automatically, the programmer can place feed and speed information on the control tape either by specifying it directly (FD and RPM) or by allowing the computer to calculate it. To calculate feeds and speeds, the programmer supplies information about the tool and the part material with TOOL and MATERIAL statements.

A typical TOOL statement is:

TOOL DRILL 2130 / D 1.5 EXT 6 FDR 7 MTL 0 RH.

This statement says that the tool is a drill numbered 2130 with a diameter of 1.5 inches, an extension or length of 6 inches, and a feed per revolution of 7 thousandths of an inch. Its material code is 0 (high-speed steel), and it has a right-hand rotation.

MATERIAL statements specify the characteristics of the material the part is made of. An example is:

MATERIAL / RSF 1.2 PFR .90 HP 4.

This says that the material has a relative speed factor (based on mild steel) of 1.2. Percent fixture rigidity is 90, and horsepower required per cubic inch of cut is 4.

The Computer System

After preparation of the manuscript, cards are punched to transfer the information to magnetic tape. This tape is the input to the first of two general parts of the CAMP II computer system (Fig. 7).

Part I decodes the statements into understandable form to the computer, stores and retrieves labeled information as required, and does the mathematical calculations necessary to convert mixed coordinates to the coordinates of the machine tool. The decoded information is then checked for completeness and accuracy according to the characteristics and limitations of the machine tool. If an error is detected, the information does not go on to Part II; instead an appropriate message is printed along with the incorrect information.

If no manuscript error is detected, the information goes to Part II through some or all of the four Part I outputs: single position and pattern, area milling, connected-path milling, and auxiliary information. Single-position output provides the information necessary to do a machining operation at one point (e.g., drill, tap, bore). Pattern output describes a single-position operation that is done at two or more points and thus requires a series of single-position outputs (e.g., bolt circles, line patterns). Area-milling output describes a rectangular volume of material to be removed. Connected-path milling output defines movement as arcs, slopes, or parallel to the machine-tool axis. Auxiliary information output specifies tool, modifier, and peripheral control functions (e.g., coolant control) that must accompany each of the other Part I outputs.

Part II is controlled from the four operation outputs of Part I. The tool path generator determines the machine-tool path that will accomplish the necessary operation and creates machine-tool movements until the operation is completed. One area-milling operation, for example, can require 50 or more machine movements. The operation master control calls upon the analysis section to make a certain machine movement. This section analyzes the machine-tool characteristics and puts out specific machine-tool commands. The output appears both as punched cards that are converted to punched control tape and as a printout of the punched control tape.

The programmer designates a particular machine tool with a BEGIN statement in his manuscript. The BEGIN statement is followed by a number assigned to the machine tool to define the characteristics of that tool. "BEGIN 1," for instance, would tell the computer to draw on the information programmed into it for the Kearney & Trecker Milwaukee-matic. The computer would then adapt the CAMP II program to the characteristics of that machine.

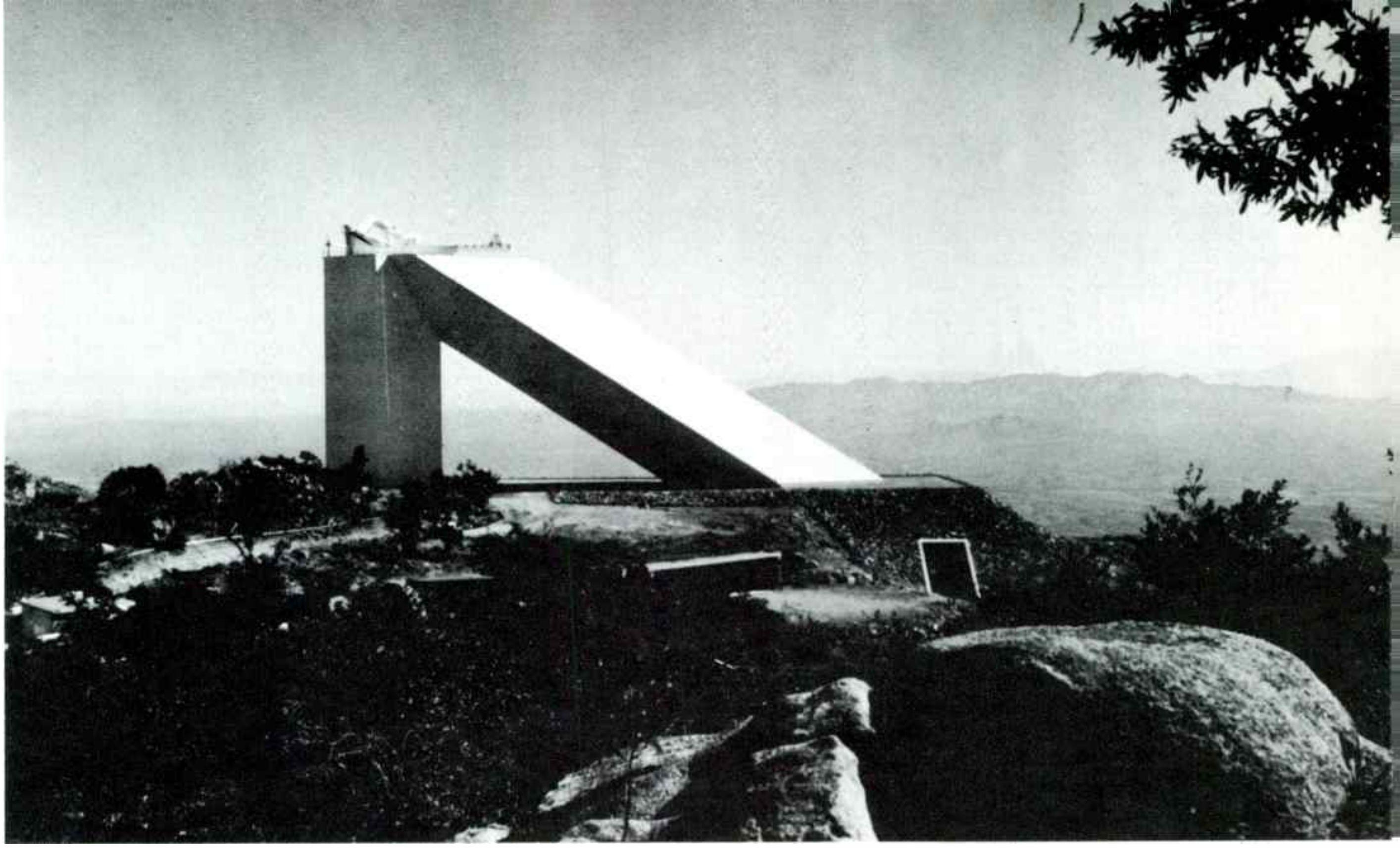
The master control and analysis sections depend entirely on Part I outputs and machine-tool characteristics for determining the path of information flow through Part II. This permits integration of a new machine tool into the CAMP II system simply by describing its characteristics. As a result, computer programming effort is much less than that in the conventional method of writing a computer program for a specific machine tool. A table of 50 to 150 constants for each machine tool is sufficient to supply these characteristics.

Conclusion

The CAMP II system has been shown to reduce programming cost by a factor of five or more on most parts. Just as important, it reduces the lead time required. Numerical control is basically a small-part-lot process. Reducing programming cost and lead time permits numerical control to be used on even smaller part lots than before, thus extending its application in manufacturing.

The language is phrased in machining and drawing terminology that covers a broad range of applications. This enables the programmer to concentrate on machining the part rather than on the detail requirements of the various machine tools he is programming. The system bridges the gap between existing drawing systems and machine-tool dimensioning requirements, reducing or eliminating the need to convert drawings for numerical control. The ease with which new machine tools can be added to the system provides a continuing cost reduction in programming and eases the introduction of new machine tools.

The CAMP II system certainly must be ranked as one of the most powerful, if not the most powerful, point-to-point programming systems written to date. Numerical control has made, and will continue to make, a great impact in manufacturing. The availability of generalized computer-assisted programming systems should aid in widening the application and extending the advantages of numerical control.



A New Solar Telescope

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Engineering Manager
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The Robert R. McMath Solar Telescope, the world's largest in several ways, is giving astronomers at the National Observatory of AURA (Association of Universities for Research in Astronomy) a new look at our closest star. Worshipped by ancients as a giver of life, but studied closely only in recent decades, the sun can provide keys to unlock vast stores of new knowledge. For example, can man predict the occurrence of solar flares, the sudden spectacular eruptions that hurl streams of atomic particles hundreds of thousands of miles into space? How is nuclear fusion, the explosive power that keeps the sun shining, controlled by the sun? What additional information can be found concerning the sun's origin, age, and position on the main sequence of the stars? AURA scientists will use this new tool in their search for answers to these and many other questions concerning our solar system.

The new solar telescope is located on Kitt Peak, near Tucson, Arizona (See *Kitt Peak National Observatory*). Such observatories are usually built on mountain tops that are surrounded by clear weather. The Kitt Peak site provides excellent "seeing" from a weather standpoint.

The telescope was manufactured, tested, and installed by the Westinghouse Sunnyvale Divisions. This is the third solar research instrument built by them; Sunnyvale had previously built two large 26-foot equatorial-mounted coronographs for the High Altitude Observatory at Climax, Colorado, and the Upper Atmosphere Research Center at Sacramento Peak, New Mexico.

Solar Telescopes

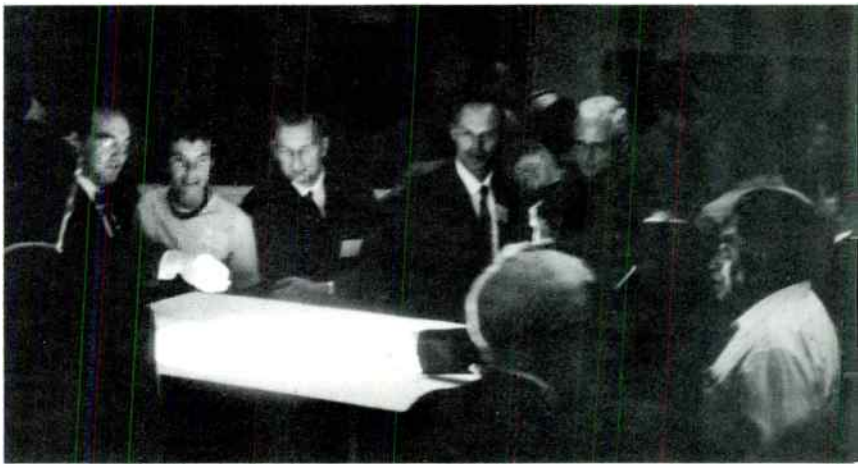
Because the sun as seen from the earth is more than 10^{13} times as bright as the brightest star, a solar telescope is constructed quite differently from the usual stellar tele-

Kitt Peak National Observatory

Kitt Peak National Observatory is operated by the Association of Universities for Research in Astronomy, Inc. (AURA, founded in 1958) for the National Science Foundation, an independent agency of the United States Government. AURA is a nonprofit corporation composed of nine American universities: California, Chicago-Texas, Harvard, Indiana, Michigan, Ohio State, Princeton, Wisconsin and Yale.

Kitt Peak, located in the Quinlan Mountains, rises from the Sonora Desert plain to an altitude of 6875 feet. It is on the eastern edge of the Papago Indian Reservation, 40 miles southwest of Tucson, Arizona, on 200 acres leased by AURA for the National Observatory. Three scientific divisions are contained within the organization structure: Stellar Division, Solar Division, and Space Division.

The Observatory's stated objectives are "to strengthen basic research and education in astronomy throughout the United States, its territories, and its possessions." Its present facilities consist of two 16-inch reflecting telescopes, a 36-inch reflecting telescope, an 84-inch reflecting telescope, and a 60-inch solar telescope. This latter facility, the largest man has made, was dedicated November 2, 1962 and named the Robert R. McMath Solar Telescope in honor of a pioneer in celestial cine-astronomy, late director of the University of Michigan's McMath-Hulbert Observatory, and the first president of AURA.



The first viewing of the largest (33.5-inch) solar image ever produced occurred on November 2, 1962.

scope. To provide an image of the sun 33.5 inches in diameter, a focal length of 300 feet is required. Because of this long focal length and the limited portion of the sky in which the sun appears (the band of the Zodiac), solar telescopes are generally mounted with their objective mirrors or lenses in a fixed position. The 500-foot building forming the Robert R. McMath Solar Telescope is inclined 31°57′ to the horizontal (Fig. 1). About three-fifths of this is underground; the 200 feet above ground is supported at its upper end on a concrete tower 100 feet high.

Light is collected by an 80-inch flat mirror (Fig. 2) mounted as a heliostat on the tower 110 feet above the ground. Sunlight striking this flat mirror is reflected southward along the polar axis at 31°57′ (equal to the latitude of Kitt Peak) to a 60-inch paraboloidal mirror located 480 feet away at the lower end of a diagonal shaft drilled into the mountain. The next reflection is 280 feet to a 48-inch mirror that sends the light into an underground observing room, where the image may be photographed or observed with spectrographs. A very large spectrograph, totally enclosed in an evacuated steel tank 73 inches in diameter and 65 feet long, provides high-resolution spectra of flares, sunspots, solar granulations and prominences.

The mirrors, the largest yet developed for solar telescopes, were furnished by the National Observatory. The mountings, including the heliostat, were built by Westinghouse. The mirrors and mountings are carried on three cars that move on a 12-foot-gage, 80-pound-rail track, which extends to the depths of the mountain below.

The upper car, which can be locked accurately in position at the top of the tower, supports the heliostat with a total track weight of 120 000 pounds. The heliostat can be lowered inside the housing with a motor-driven hoist so that the cover can be rolled over the top during inclement weather; the heliostat car can also be lowered to the aluminizing room, located some 90 feet down slope from the observing room.

The heliostat mounts the 80-inch flat mirror, which weighs 4200 pounds, on two axes—polar and declination (Fig. 2). These two degrees of motion allow the mirror to be pointed at the sun as the earth rotates and as the sun shifts in its diurnal motion. Mirror motion is accomplished by means of a 45 000-pound polar yoke, supported by a north-end ball bearing and a 120-inch south-end hydrostatic ring bearing that allows passage of the sun's rays. Four hydrostatic pad bearings, 14 inches in diameter, support the south-end ring on an oil film 0.005 inch thick, supplied at an operating pressure of 500 to 600 psig.

Normal rotation of the yoke in right ascension is one revolution in 24 hours. Its maximum or slew rate is two degrees per second. The yoke is driven through an extremely accurately generated 90-inch-diameter cast iron gear wheel driven by a hardened 3¼-inch-diameter worm gear (and other reduction gears) from a ¼-hp motor. A precision clock drive paces the heliostat on its right ascension motion.

The declination drive, which requires only minute changes daily, consists of an air motor with a reduction gear, a 26-inch-diameter gear driving a 2½-inch-diameter worm for fast motion, and an 8-foot tangent arm drive for slow motion.

Controls for the heliostat are located both at the top of the tower and in the observing room at the master control. Electronic guidance from a photoelectric device keeps the sun "on target." Computer guidance is also possible from tapes that can be cut to track the sun each day of the year.

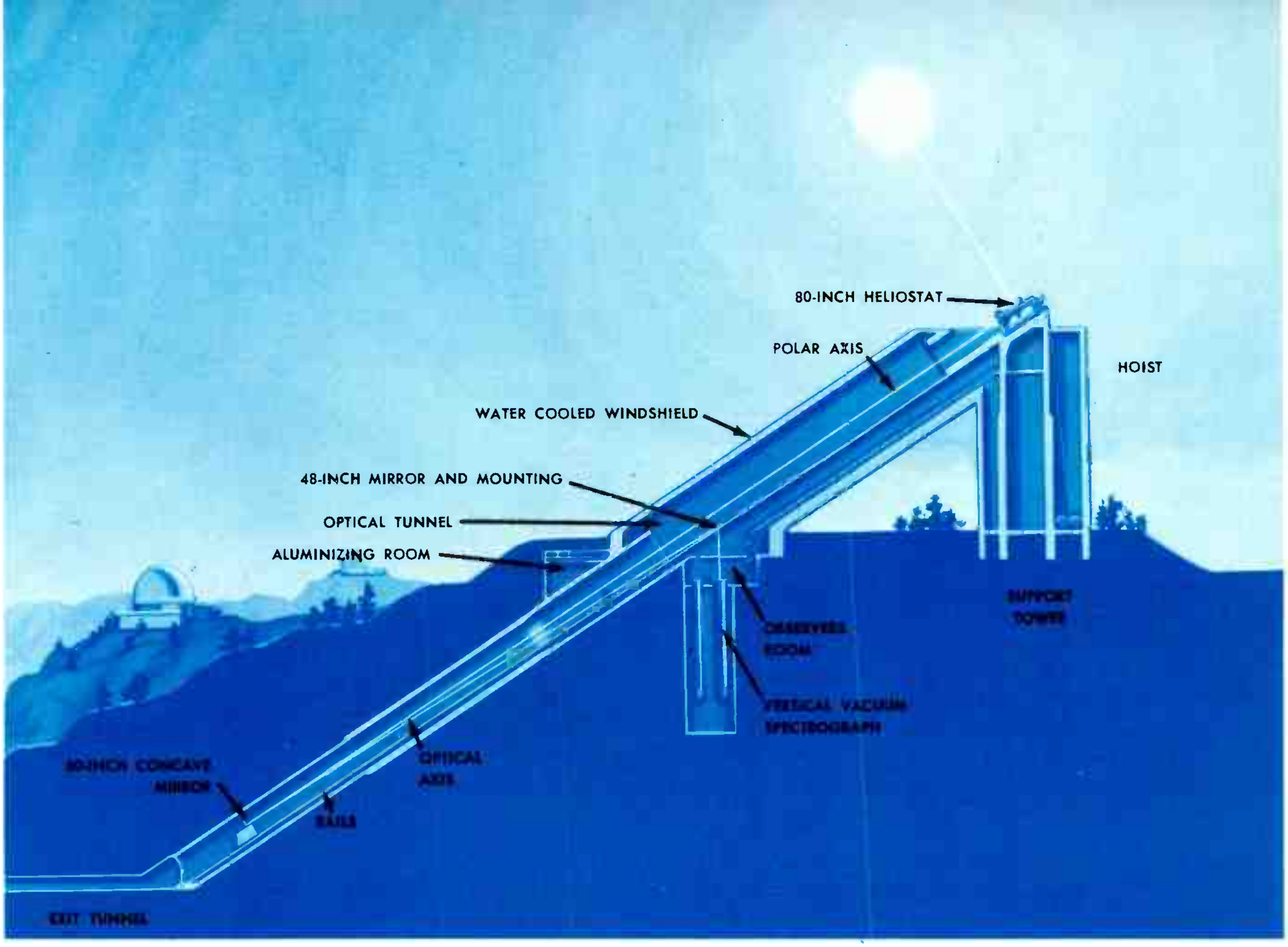
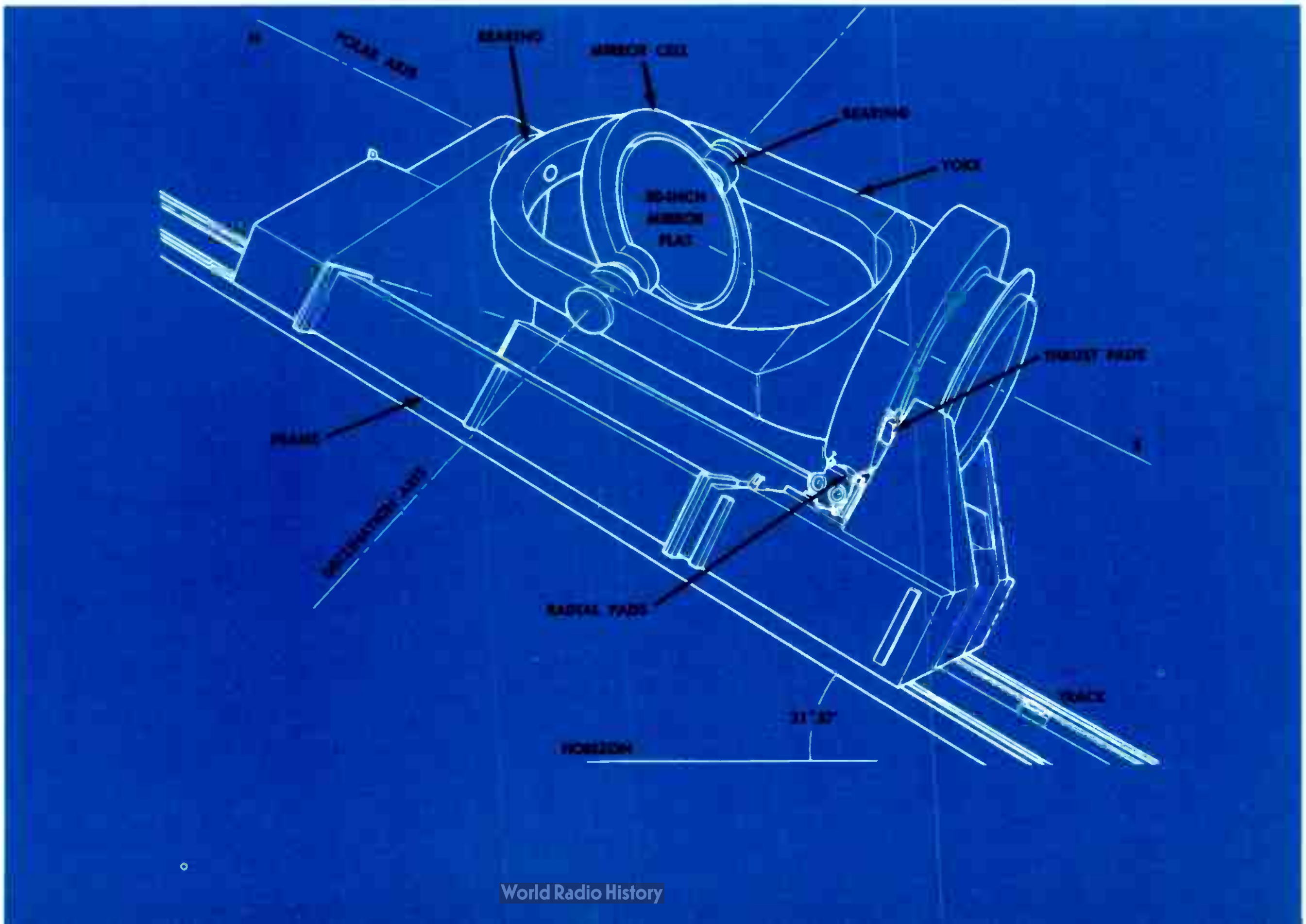


Fig. 1 Arrangement of the Robert R. McMath solar telescope.

Fig. 2 Diagram of the heliostat, which tracks the sun.



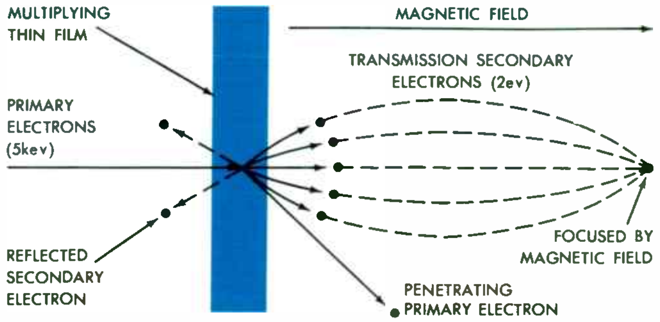


Fig. 1 (Above) The impact of primary electrons causes secondary electrons to be ejected. In normal targets, most of these secondary electrons are reflected. However, if the target is a thin film, secondary electrons will be transmitted through the film.

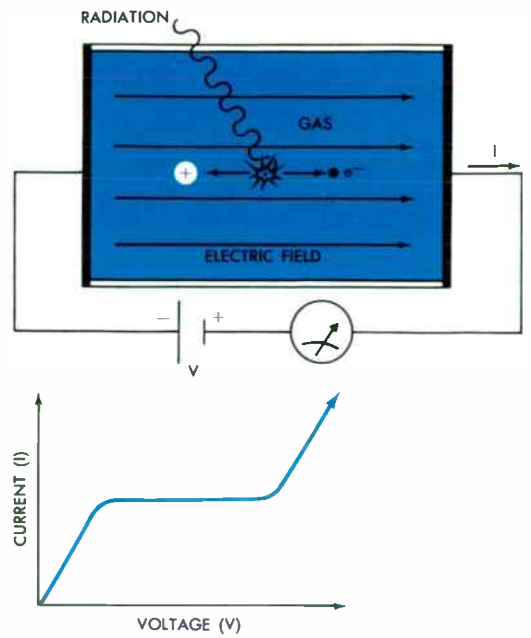
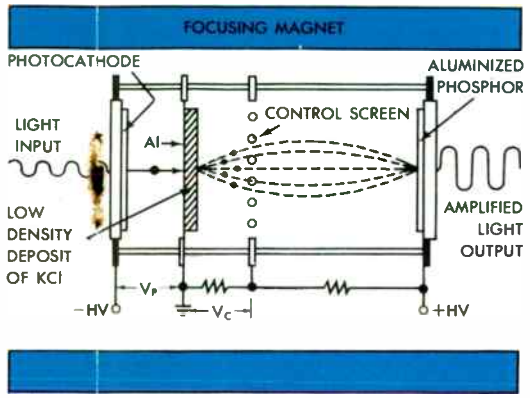


Fig. 2 (Right) The voltage applied to an ionization chamber causes a current to flow. If the voltage is increased sufficiently, a great increase in current results from avalanche effect.



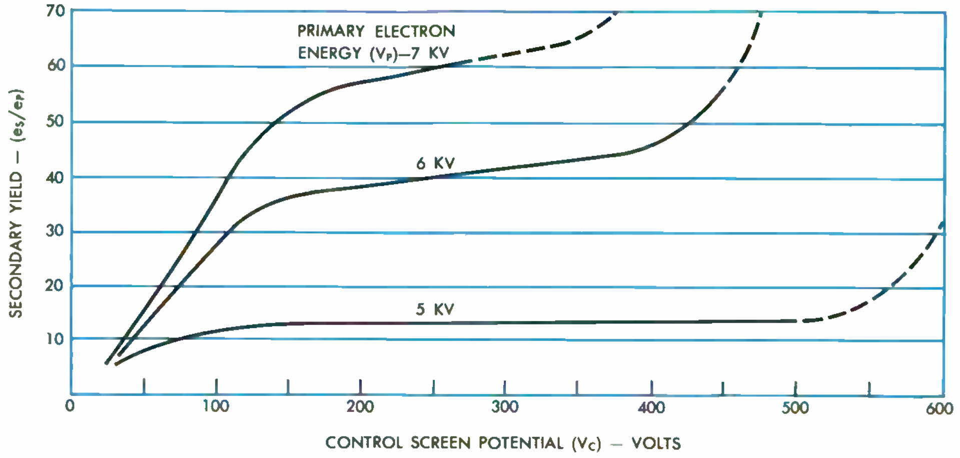


Fig. 3 (Left) This cross section of an image amplifier demonstrates the operation of a high-gain thin-film dynode.

Fig. 4 (Above) Secondary yield of a low-density KCl dynode varies with collecting voltage and primary electron energy.

LOW-DENSITY FILMS AND ELECTRON AMPLIFICATION

The Astracon, a light amplifier so sensitive that it makes visible every photon of light that triggers its input, was the first of several new electronic devices made possible by recent developments in thin-film techniques. The first version of the tube, based on an electron multiplication principle perfected by the Westinghouse Research Laboratories in 1960, produced an electron amplification of 3000 with five stages of thin-film amplification; the most recently developed films have demonstrated electron amplification of 2500 with only two stages. The improved amplification per stage was made possible by a recent development in thin films, a low-density solid film so light that 98 percent of its volume is nothing.

Transmission Secondary Emission

Electron amplification in a thin film is accomplished by a mechanism known as *transmission secondary emission*, illustrated in Fig. 1. Although the principle was known in the late 20's, its practical application had to wait for development of techniques for making extremely thin films covering a useful area. The initial investigation at the Westinghouse Research Laboratories was done by Dr. E. J. Sternglass, who developed the first fundamental patents for present thin-film technology in 1954. His multiplying films were first put to use in the Astracon image amplifier.

The thin-film electron amplification principle can be applied to any imaging device where the image can be converted to an electron pattern. The electron pattern is focused on the multiplying film; secondary emission electrons from this film are focused on the next stage by a magnetic field. The output electrons from the final stage are accelerated to a phosphor surface, causing the surface to glow and to reproduce the original image greatly brightened.

Until recently, most multiplying films (or dynodes) were "sandwiches" consisting of an active secondary emitting layer of potassium chloride, which is vacuum deposited on a supporting film of aluminum oxide and aluminum. The fundamental limitation of this type of solid KCl film is that it produces a maximum of only 6 to 8 secondary electrons for each primary electron.

A greater secondary electron yield has a number of advantages: First, if the number of stages of amplification can be reduced without reducing overall gain, better resolution can be obtained. Second, contrast degradation is a function of the ratio of penetrating primary electrons to true secondary electrons (Fig. 1). Because the energy of the penetrating primaries is so much different from that of the true secondaries, the penetrating primaries are not focused from stage to stage. Therefore, the penetrating primaries produce a general background at the tube output, and can seriously limit the detectability of a weak image against a high image background. Higher secondary yields increase the ratio of secondaries to penetrating primaries, and improve contrast performance. And finally, if dynodes can be made to develop a higher secondary yield at the same primary voltage per dynode, tube voltage can be lower for the same overall gain.

Field-Dependent Secondary Emission

Scientists[1] have known since about 1940 that greater secondary yields can be obtained when internal electric fields exist in the secondary emitting layer to enhance the emission process. For example, high yields were observed in secondary reflection (as opposed to secondary transmission) by Jacobs and coworkers[2] from porous magnesium oxide layers when the layer surface was positively charged. These investigators reported unusually high secondary emission ratios, up to 10 000 to 1. However, their explanation of the mechanism causing these high gains differs fundamentally from the standard secondary emission phenomenon. The process was described as similar to that of a Townsend avalanche; a true secondary electron is accelerated sufficiently by the field *within the layer* to produce additional electron multiplication by an avalanche process. This field-dependent secondary emission effect was not investigated at that time for transmission secondary emission; it appeared that this type of emission could not be used for imaging purposes because of the "noise" that accompanies the avalanche mechanism.

However, the good agreement between the experimental evidence given by Jacobs and his hypothesis of a Townsend avalanche in the porous layer suggested further investigation: Since an extremely porous layer may be thought of as a gas of rather large molecules under high pressure, the effect observed by Jacobs might be comparable to the operation of an ionizing chamber (Fig. 2). If the operating conditions could be such that the internal field within the porous layer would enhance the escape probability of secondary electrons without causing additional ionization (avalanche), secondary yield should be improved. The investigation of this possibility was begun at the Westinghouse Research Laboratories under the direction of Dr. Gerhard W. Goetze in 1960.

Low-Density Films

The solid potassium chloride films are made by vacuum evaporating potassium chloride onto the aluminum substrate. To investigate the new possibilities of low-density films, a very porous layer of insulating material (such as potassium chloride) is needed, with a density one or two orders of magnitude below that of the normal solid film. This porous film is obtained by evaporating potassium chloride onto the aluminum substrate in an argon atmosphere of 2 mm Hg, rather than in a vacuum. The density and structure of the porous layer varies with argon pressure, distance between the evaporating crucible and the substrate, substrate temperature, and rate of evaporation. The porous film is actually a smoke deposit—a thin fluffy layer about a thousandth of an inch thick—and so porous that it is 98 percent empty space.

The operation of a low-density film is illustrated in Fig. 3. The situation believed to exist in the porous KCl film is as follows: As a result of secondary electrons escaping, a positive charge is built up near the exit surface of the film, producing an internal electric field across the film. This field imparts a drift velocity to the secondary electrons emitted toward the exit surface. The maximum potential which the exit surface can assume with respect to the aluminum substrate is that of the control screen. Under this condition, the electric field across the low-density layer becomes V_c/d, where d is the layer thickness. Since d is very small, about 10 microns, this field can be very high.

Typical secondary yields obtained with low-density films are illustrated in Fig. 4. It can be seen that secondary yield is a function of both control screen voltage (V_c) and primary electron energy (V_p). The curve shape is suggestive of the characteristic current-voltage curve for a gas discharge—initial rise, a plateau, and then a steep rise in current due to avalanche effect. From Fig. 4, it can be seen that for a given film, the maximum voltage that can be applied to the control screen is decreased if primary electron energy (V_p) is increased. This suggests that the primary electrons penetrating deeper into the porous layer effectively reduce layer thickness, causing the electric field strength near the exit surface to increase.

Response Time

A finite time is required to charge the exit surface of the thin film up to the collecting electrode potential V_c, and to obtain a stationary secondary yield. During this time, a steady increase in yield from initially low values is observed.

Because of the very high resistivity of the thin layer, the film can be charged over a long period of time—perhaps several hours—if the incoming current density is low. This ability to accumulate charge over long periods makes the film ideal for use in camera tubes or storage tubes, where pattern storage or signal integration is needed.

Once equilibrium is established, the surface charge does not deteriorate for many hours, again because of the very high resistivity of the thin film. Hence, for image amplification or counter applications, the tube is initially flooded (or primed), so that from this point on, time response to incoming electrons is extremely fast (about 10^{-9} second).

From the observed properties of the porous films, scientists have concluded that the internal electric field in the insulating film makes it possible to extract a large fraction of all secondary electrons formed by the primary ionization mechanism. The phenomenon of field-enhanced emission from low-density films will need further investigation before the physical principles are completely understood. However, the effect is already being put to use in several advanced forms of electronic tubes.

Westinghouse ENGINEER May 1963

Two typical references to secondary yields in the presence of internal electric fields:

[1] K. G. McKay, *Advances in Electronics*, Academic Press, New York, 1948, p106.

[2] H. Jacobs, J. Freely, and F. A. Brand, *Phys. Rev. 88*, 492 (1952).

Programs for Power System Computing

A large library of computer programs now exists for solving power system problems; improved data organization and financing will be needed to accommodate the more extensive programs to come.

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Much of the progress of the electric utility industry can be attributed to its ability to recognize and solve system problems—the network problem, the stability problem, the machinery problem, and others. Solution of these complex system problems has required the use of computers—first the dc- and ac-network calculators and now the internally-stored-program digital computers. The industry is influenced profoundly by the advances taking place in scientific data processing, in simulation, and in the new and powerful mathematical approaches coming from theoretical developments in the information system sciences.

Progress in Industry Technical Computing

As power systems have increased in complexity, computing techniques have kept abreast of the needs of system planners and designers. The ac-network calculator was the workhorse of the power industry for many years for studies of power flow, short circuit, transient stability, loss evaluation, and economic dispatching. However, in the past ten years the digital computer has slowly taken over the function of the network calculator, although this direct system analog will continue to serve a useful function for many years. These studies have now become members of a large library of digital programs that enable system planners and designers to do a better job of technical and economical analysis.

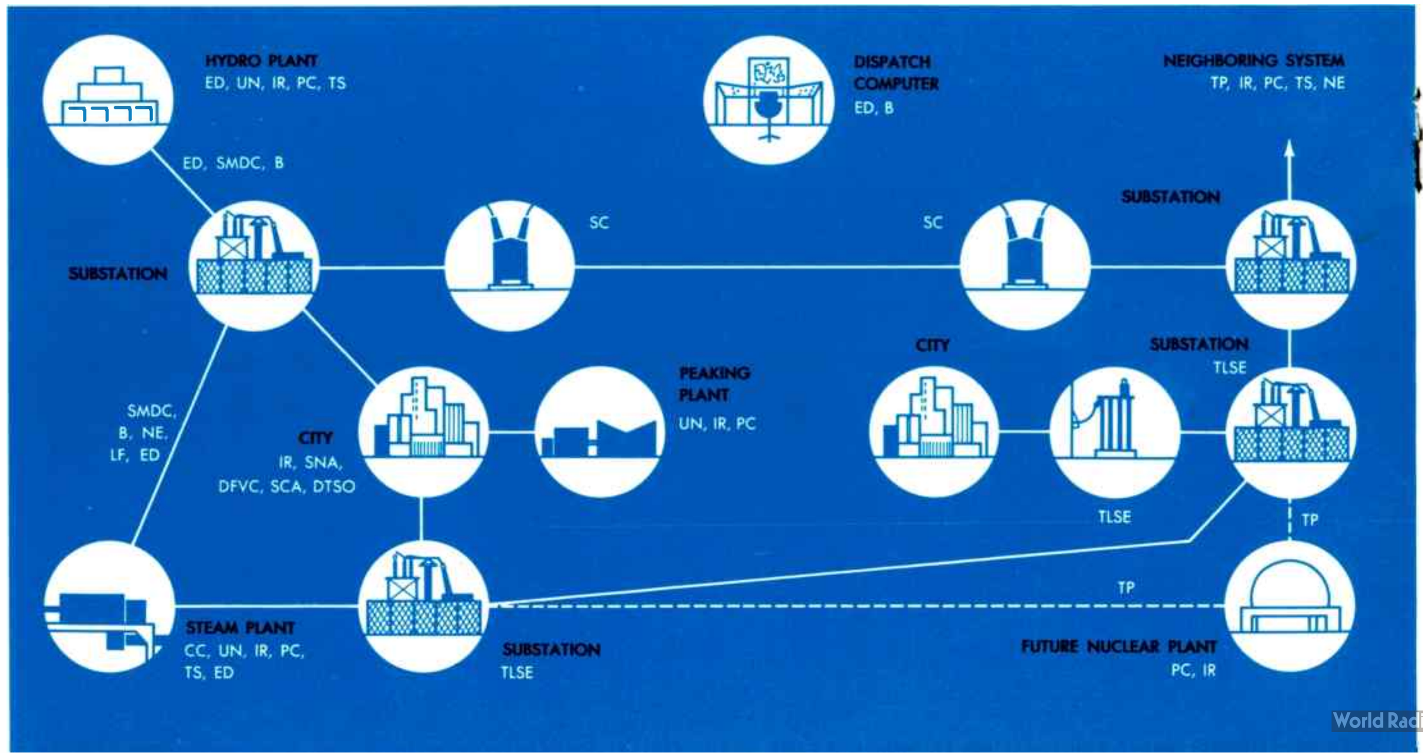
The programs now available at a typical service bureau library can be grouped into *generation*, *transmission*, and *distribution* planning programs. While many other programs exist throughout the industry to do specific jobs, those described here are general-purpose for application to a great number of different systems. The specific programs mentioned are used with the IBM-7094 computer at the Westinghouse computer center.

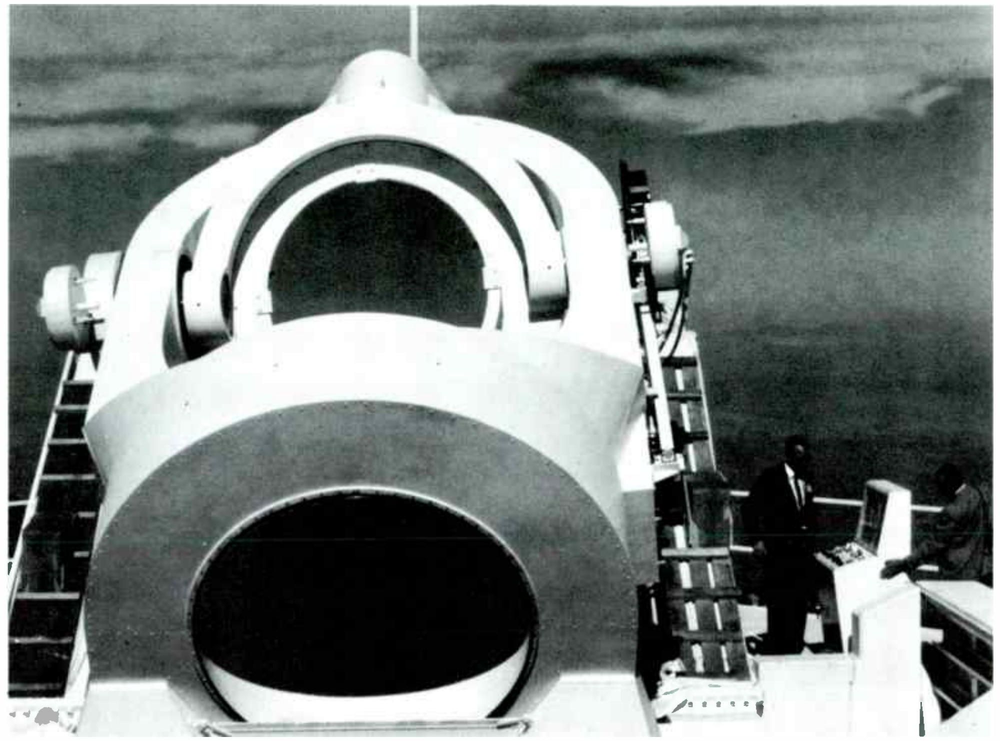
Generation Programs

Cost Curve—Incremental cost curves are developed from incremental heat rate curves. The program is capable of combining several unit heat rate curves into one station cost curve. Up to 60 heat rate curves can be handled to form up to 50 cost curves. From two to six units can be combined into a single curve. The program is fast and is useful in preparing station cost curves for the economic dispatch program.

Economic Dispatch—This program uses the loss formula B_{mn} coefficients and station cost curves to obtain an economic dispatch solution. An iterative procedure is used to obtain the proper *lambda* (λ) and resulting generation for each station. The program can handle up to 55 stations with up to 40 of them being variable.

Unit Selection—An economic shutdown rule program shuts down units from a priority list in each hour until the load-plus-spinning-reserve requirements are satisfied. It finds the optimum shutdown rule-of-thumb by determining the production costs by economic dispatch for a number of





View of the 120 000-pound heliostat assembly, in position atop the 100-foot tower.

The image-forming 60-inch-diameter f/60 paraboloidal mirror has remotely controlled focusing motion parallel to the track; pointing is also remotely controlled. The 48-inch mirror mount is pointed by remote control. All mirrors are made of fused silica, selected because of its low thermal expansion, and are held in their mounting cells by a vacuum system.

Special problems associated with this telescope were the heat dissipation and temperature control of both the optical components and the extremely long air path of the light. A special titanium oxide white paint with high albedo protects the mounting and wind-shield structure from the sun's heat. Warm air rising from the ground or from buildings would cause poor "seeing." Therefore, unique features were provided to overcome this difficulty—tower mounting, and a system for cooling the outside surface of the surrounding building to ambient air temperature to prevent interfering air turbulence.

The concrete tower, designed to raise the heliostat above the shimmering ground air convection currents, is isolated from its surrounding wind shield, whose walls are copper water-jacketed. The water jacket is made of tube-in-strip panels, through which a mixture of water and glycol circulates from a 15 000-gallon storage tank (cooled by night sky radiation) to maintain temperature uniformity of five degrees or less between the outside and inside of the structure at all times. A 40-hp, 13.3-ton refrigeration unit cools the tunnel lining, particularly during the winter season when the surrounding rock retains its more or less constant temperature of 65 degrees F.

Since frequent thunderstorms occur during July and August at the Kitt Peak site, special precautions have been taken to protect the instrument, structure, and personnel. These include a folding mast mounted on top of the tower, good bonding throughout the structure, and counterpoise extending around the area because of poor grounding provided by the weathered granite mountain top.

Solar Studies

Geophysicists have been studying the sun for a number of years. They have learned, for example, that the solar flares provide high-energy particles that become trapped in the earth's magnetic field, forming radiation belts that may pose a serious threat to space travelers. They would like to be able to predict the "solar winds" that caused Pioneer II to deviate from its course, or determine optimum launching times.

The release of high-energy particles from the sun is usually followed by magnetic storms on earth and by blackouts of long distance radio communications. There is also tentative evidence that solar particle clouds sometimes intensify storm centers over North America and force them to the south.

But the most practical reason for studying the sun is to learn more in the field of nuclear fusion. With the new solar telescope, scientists hope to collect more clues on just how the sun controls the fusion process. With the aid of the spectrograph, small segments of the sun's light can be analyzed, giving new insight into the violent physical changes that take place on the sun's surface, and perhaps even deep in the core. Studies will be made of sun spots, flares, prominences, and solar granulation. Physical measurements may be taken of the sun's atmosphere, pressure, temperature, density and chemical composition. The McMath Telescope will bring a new order of certainty into solar research.

rules. Startup costs are handled in the calculations. Another technique, dynamic programming, develops up to 30 combinations of operating units for each hour. Each combination is then dispatched considering penalty factors. The total cost, both production and startup, is combined with the cost of each combination of the previous hour to obtain the best combination for the previous hour. The program can handle up to 50 units.

Installed Reserve Evaluation—This reserve planning program secures the generating unit forced outage distribution by analytical mathematical means, combines it with load distribution, and evaluates risk of insufficient installed reserve from the resulting probability distribution of installed reserve margin. The program automatically plans maintenance on a unit-by-unit basis. Risks are evaluated to signal the addition of a new unit. Other routines are available to evaluate risk to a system or pool interconnected by a limited tie of specified value to another system or pool of known make-up and load characteristics. These routines can be used to plan tie expansions between pools along with unit additions. This reserve evaluation program can evaluate expansion patterns for 1 to 40 years into the future for systems of 400 units or more.

Production Cost—Many varieties of production cost programs are available. One general program can be operated independently or as a subroutine of the installed reserve programs. It will evaluate the cost of fuel, operation, and maintenance incurred by systems over any period of time up to 40 years. It can be used with systems containing all types of fossil-fuel units, nuclear units, hydro run-of-river, pondage, and pumped-storage units in a wide range of proportions. Costing is done on a weekly basis using incremental cost curves and weekly load duration curves segmented into periods of several hours each. When several systems are costed, the dispatch is performed for the combined pool, after which economy interchange between systems is determined and costed.

A more complex program evaluates the cost of fuel for periods from 1 to 24 months for short-range planning and budget purposes. It is suitable for fossil-fuel units and nuclear units. Up to 75 such units can be considered. This program was developed to accurately simulate system operation by considering must-run units, maintenance schedules, weekend shutdown units, area protection requirements, and economy interchange transactions. It can dispatch two systems combined and determine the economy interchange between the two, and the average cost of the economy energy. The program can also evaluate the amount and cost of economy sales from the two systems to a third system. Incremental costing is used with five daily two-hour integrated load curves to represent a seven-day week. Computed results have duplicated actual fuel usage for a particular system within one percent.

LEGEND

CC	cost curve
ED	economic dispatch
UN	unit selection
IR	installed reserve evaluation
PC	production cost
SMDC	self- and mutual-drop coefficients
B	loss formula
LF	load flow
SC	short circuit
TS	transient stability
NE	network equivalents
TP	transmission planning
TLSE	transformer loading and substation expansion
SNA	secondary network analysis
DFVC	distribution feeder voltage correction
SCA	shunt capacitor application
DTSO	distribution transformer and secondary optimization

Fig. 1 Applications of the various computer programs on the power system are shown on this symbolic system diagram.

Transmission Programs

Self and Mutual Drop Coefficients—Two programs are available: The first can handle 200 nodes (buses), and uses a double-precision matrix inversion technique to obtain the coefficients; the second and much faster program can handle 100 nodes and uses a mesh equation method to obtain the coefficients. These programs are used primarily to obtain information for the loss-formula program.

Loss Formula—This program determines the transmission loss formula B_{mn} values for economic dispatch purposes. These values are derived from the self- and mutual-drop coefficients. The program can handle systems of up to 55 stations and 150 buses.

Load Flow—The common nodal equation iterative method of solution is used to solve the general power flow problem. The program has the following special features: User-specified mw accuracy criteria; bus voltage angles referenced to any value at any bus; automatic tap changing to hold specified terminal conditions; phase-shifting transformer representation; mvar limits specified for any or all generators including the swing machine; bus voltage controlled by a generator at a remote bus; and consecutive cases with specified branches changed, or generation and loads varied, or both, selected automatically.

Short Circuit—Network voltages and currents can be calculated for either three-phase or single-line-to-ground faults. Provision is also made for calculating faults on the line terminals of an open circuit breaker and for calculating faults following the removal of lines due to breaker operation or scheduled line outages. The program can consider any or all of four fault types: bus fault, fault with every line or source on the fault bus out one at a time, line-end fault on every line connected to the fault bus, and special faults as specified.

In addition, a variety of printouts of current and voltage can be specified in any combination for any fault bus; for example, currents in every line or source connected to the fault bus, or to it and every adjacent bus, or to it and every bus that is one and two buses away, or currents in every line or source in the system, or just specified currents. A variety of voltages can be selected, too, and these output combinations simplify the data requirements. The program can handle systems up to 200 buses and 300 lines plus sources. It uses the mesh analysis technique, the fastest yet developed.

Transient Stability—A matrix reduction and modified Euler method is used to obtain the angle-versus-time curve

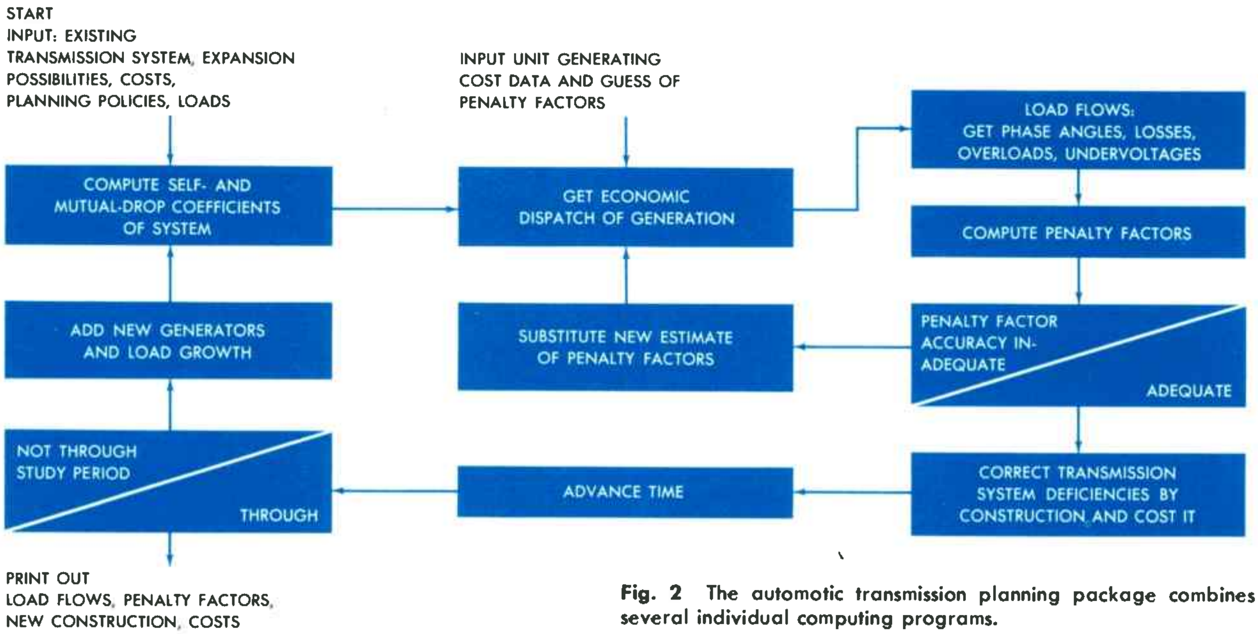


Fig. 2 The automatic transmission planning package combines several individual computing programs.

for each generator following a system disturbance. Both synchronous and induction machines may be considered for systems of up to 190 buses, 380 branches, and 40 machines. The program starts with the initial conditions determined by the load flow program, and approximately 90 percent of the input data can be automatically punched on cards by the load flow program.

Network Equivalents—Both positive- and zero-sequence equivalent networks can be determined for systems of up to 190 buses and 380 branches. The positive-sequence equivalent program uses circuit reduction techniques to obtain equivalents for any of three types of studies: load flow, short circuit, and transient stability. The zero-sequence equivalent is obtained from the short-circuit program. Up to 40 buses can be retained for either equivalent.

Transmission Planning—This program plans and costs the transmission requirements for a 20-year generator expansion and load growth pattern. The program consists of three sub-programs: economic dispatch, load flow, and transmission logic. Generators, transformers, or lines may be added by date; and load flows, normal and emergency, are performed by date. If a load flow reveals buses with low voltages or overloaded lines, construction is performed to alleviate the trouble. Additional load flows are performed after each step of construction to test its value. If the construction does not correct the trouble, it is removed, and another type of construction is tried. Four voltage levels can be considered simultaneously, and any three of these can be planned automatically. Ultimate systems of 210 buses, 350 lines, and 80 generators can be handled.

Transformer Loading and Substation Expansion—The load, energy losses, hot-spot temperature, and accumulated loss of life for each transformer are determined each hour considering unbalances between transformers, planned outages, and forced outages. Planned, short-forced, and long-forced outages are scheduled randomly, and multiple outages are permitted. When the accumulated loss of life of any transformer exceeds 100 percent, it is replaced with a new unit. The substation load is allowed to grow along an area annual trend line. When the risk of any transformer exceeding its hot-spot temperature exceeds an input value, a new transformer is added; or if no additional transformers are permitted, the load is levelized. Load is levelized by keeping future yearly peak loads equal to the peak of the year previous to that in which the risk level was exceeded. The program can handle up to a ten-bank station for up to 40 years.

Distribution Programs

Secondary Network Analysis—System bus voltages, line power flows, and transformer loadings are determined with this secondary network load-flow program. The program uses the nodal-equation, iterative-solution technique. It can accommodate a system having a maximum of 250 buses and a combined total of 500 lines and transformers.

Distribution Feeder Voltage Correction—The application of fixed and switched capacitors and line voltage regulators to primary feeder circuits for voltage correction is optimized. The program compares the entire feeder voltage profile to the maximum and minimum acceptable voltage values and applies the minimum cost combination of line regulators and fixed and switched capacitors to correct the profile. The limit of the program is a feeder consisting of a main trunk with 20 nodes and 10 lateral branches, with 10 nodes on each lateral branch.

Shunt Capacitor Application for Var Control and Loss Reduction—This program consists of three subprograms, which have been written to utilize new basic theory recently developed. The theory provides equations and techniques to optimize the ratings and locations of fixed and/or switched capacitors on primary feeder circuits. The subprograms consider simultaneously the effects of energy losses, peak losses, and relative costs of fixed and switched capacitors.

Distribution Transformer and Secondary Optimization—Several existing programs can optimize the application of distribution transformers and secondary circuits to residential load areas. These programs may take load growth and alternate methods of load relief into account to determine the most economical design. Results of these studies can be used to establish and evaluate system design standards and operating practices.

Integration of Programs into Larger Packages

A state of advanced development has been reached with most of the individual service bureau programs described above. More recent development effort has been aimed at the integration of individual programs into larger packages to automate the calculation of problems of ever-widening scope. Some of the individual programs are naturally used together. For example, the *self-* and *mutual-drop coefficient* program provides information for the *loss formula* program, which in turn provides input information for an *economic dispatch* solution. As another example, the *transient stability* program makes use of equivalent networks arrived at by network reduction using matrix techniques. Thus, the *network equivalent* program is but a subroutine for the *transient stability* solution. In addition to these obvious combinations, there have been more far-reaching developments in the integration of programs into larger computing systems. These advances are taking place in the areas of automatic transmission planning, bulk-power system planning, and distribution planning.

Automatic Transmission Planning—Great progress has been made in the past three years in the automation of transmission planning through the integration of several of the general programs already described. Features of the resulting packaged program have been briefly described above under *Transmission Planning*. However, because of the significance of this development and prospects of its future expansion, this program warrants more detailed discussion. Basically, the overall transmission planning program is a combination of five subprograms: Self- and mutual-drop coefficients, loss evaluation through penalty factors, economic dispatch, power flow, and transmission expansion logic. A single set of input data is used for the overall program, and there is no human intervention as the program shifts from one subprogram to another.

The program is capable of planning a 20-year bulk-power transmission system expansion, including a certain amount of optimizing of specific line selections and of costing new construction. The self- and mutual-drop coefficient subprogram (Fig. 2) prepares input data for the subprograms that compute transmission loss penalty factors for each generating station. With these, the economic dispatch subprogram is used to determine how much generation should exist on each bus for a specified system load. Then the power flow is used to (a) detect overloads or low voltages on the transmission system, (b) to check on the effectiveness of the transmission changes proposed by the transmission logic subprogram, and (c) to evaluate transmission losses. The transmission logic subprogram determines what modifications or new construction is needed to alleviate the transmission overloads or low-voltage situations discovered by the power-flow program.

As transmission is constructed or modified, the program outputs a record of these changes including their cost. Specifically, a statement is printed that indicates what was built, why it was built, and its cost. At the end of each month the total expenditures for the month are given. Finally, revenue requirements for transmission expansion are computed.

Bulk-Power System Planning—A number of the individual programs are used to accomplish long-range planning of bulk-power systems (Fig. 3). One important part of the computational process makes use of the automatic transmission planning package already described. However, this package works in conjunction with two other programs, the *installed reserve evaluation* program and the *production cost* program. In practice, a load reduction program is used to provide common input load data for the installed reserve evaluation, the production cost, and the transmission planning programs. Then the production cost program receives input data automatically prepared from two other sources: year-by-year penalty factors are automatically computed for it by the transmission planning program, and a weekly maintenance schedule for the long-range planning period is input to it by the installed reserve evaluation program. Thus the several programs work together as an integrated package for the planning of long-range expansion of a bulk-power system. This package makes use of all or parts of seven of the individual programs previously described.

Distribution Planning—The integration of distribution planning programs into a single package has been started. A sample distribution system optimizing program has been written that uses the technique of geometric simulation. The simultaneous consideration of all interdependent system components and associated design variables such as system voltage, substation ratings, conductor loadings, and conductor sizes is made possible through the use of a model system in geometric patterns. While uniform conditions are assumed with no load growth, this program may be used to evaluate alternative design variables and as a guide to distribution system planning policies. It incorporates features of the distribution transformer and secondary optimization program. Building on this initial effort at integrated distribution planning, additional work of a more advanced nature is under way.

System Data

The handling of system data has simply not kept pace with the tremendous ability to process it. The organization and systemization of power system data for analysis and control purposes represents one of the most important but most difficult problems of the future. It must be solved if the computer power at hand is really to be used efficiently. A number of years ago, the first step of any system study was to calculate most of the impedances; zero sequence was unknown. The ac-network calculator brought together good lists of impedances with a clarified nature of the presentation through voltage base, mva base, and the treatment of transformers and even phase shifters. As a result, all the usual information for making standard network calculations is quite readily available. Most systems also precalculate the equivalents to use for their studies and keep them up to date.

However, total data organization must be improved if the industry is to move on to cope effectively with the greater problems of the next computing era. Just as the powerful matrix notation enables one to use a single letter for a vector or matrix, so one should be able to enter a computer, any computer, with a standardized format data block that provides the input in large, readily available building blocks for any of the common system problems. System planners should understand what these blocks are to be used for so that they can be standardized in the industry and kept up to date on a simple clear-cut basis. For example, the power system growth problem has the possible alternatives of pumped hydro, gas turbines, nuclear plants with various types of cycles, interconnections, and others. System planners need to turn their attention to the matrices of quantities that are needed to solve these problems. Perhaps they need a generator data matrix, a transmission line data matrix, a transformer matrix or vector, a load vector, and a reliability vector. A data matrix or vector would define an element of the system that is important in one or more of the planning problems. It would enable entry into the data maze with a single handle rather than with as many different handles as there are problems.

List-processing is a new technique for entering all of the pertinent data about every element involved in a system and drawing this out in formats required for different purposes, all automatically. The list-processing programs draw reports compiled in a manner easily specified in compiler language. One such report could be the complete input required for a load-flow problem on a stability problem.

The handling of data, of course, becomes particularly critical in very large problems. In the representation of extremely large systems not all parts can be included in the detailed representation for the particular problem, and equivalents of some kind are necessary. Since the complete system does have a specific performance under any conditions, the computer can work in an adaptive fashion if the data can be entered adequately and in condensed form. Then the computer can go as far back into the system data as there is any major influence on the problem at hand. Quite possibly, all of the data about a particular system might be in a small memory package which is plugged in, and the same would be true for other peripheral systems. The "plugging in" might be physical or logical.

A New Attitude Toward Power System Computing

In the electric utility industry, a substantial amount of research and development has been done by the electrical manufacturers. A close tie has always existed between the two elements of the industry in developing and working on important application and operating problems. The mutual development of computer programs associated with these problems is particularly advantageous for it engenders a common understanding of the systems for which the equipment is being developed and applied. Now there are impending changes in power system computer applications. These involve the expansion and integration of programs, the extension to control computers, the use of linked computers, and the effective utilization of all of the developments taking place in information processing. These changes pose not only great problems but also great challenges and opportunities in which even closer cooperation can be secured.

A new attitude is required toward power system computing if the challenges are to be met and full advantage taken of the opportunities presented. For one thing, the real value and real cost of programming must be recognized; software must be treated somewhat like hardware with respect to its production and financing. Sharing of ideas and papers recounting technical progress is a normal part of professional interchange—it begets progress. But the larger and more effective production programs for major engineering work, major planning studies, and for control computers must be supported by sound financing and organization. The industry trend to purchase the programs for control computers along with the computers is a step in the right direction since it provides for well-planned organization and development of the necessary programs, similar to the equipment itself. Scientific and engineering programs are due the same treatment.

Many large and complex pieces of work lie ahead both in the integration of programs into substantial programming packages and in the data organization that must accompany the more extensive information processing to come. The industry must recognize the value of techniques and programs that are developed at great cost quite independent of hardware sales, and provide financing for this work in a manner that will result in more effective use of the talents now available in both manufacturer and utility organizations.

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Photo Westinghouse computer center at East Pittsburgh.

Bow Thruster Drives and Controls

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Electric motors for ships' bow steering devices can be sized economically by taking advantage of the intermittent nature of operation and the motor's short-time overload capability.

Bow steering devices are becoming increasingly popular for standard type ships, and they have won a place as essential equipment in many special-purpose vessels. These steering devices, called bow thrusters, create a lateral force on the forward part (bow) of a ship. They are used to increase maneuvering capability, especially at low speed, and to prevent undesired swinging of the bow by tide, wind, or current.

Increased maneuverability increases the self-sufficiency of standard type vessels (those intended for cargo or passenger service) by helping them dock at ports that lack adequate or reliable tug assistance. It also facilitates transit of narrow channels and lock systems, such as the St. Lawrence Seaway. The result is decreased turnaround time, which increases the productivity of the vessel and is an important factor in view of present conditions of high operating costs and high initial investment. Increased self-sufficiency also saves in tug fees—one Great Lakes ship operator expects the savings in tug fees alone to pay for the initial cost and installation of the bow thruster (about $100 000 for his ship).

Special-purpose vessels benefit in the same ways as the standard vessels and, in addition, many of them have special position-keeping and maneuvering requirements that make a bow thruster essential. Oceanographic survey ships, for example, need precise positioning ability for certain studies. Dredges and off-shore drilling barges need the same ability for their operations. Cable ships must operate at low speed and maintain an accurate course while laying cable. Buoy tenders must hover alongside large buoys in all kinds of weather while the crew services the buoys.

Several types of devices have been used for bow steering. Some of these are the bow rudder, waterjet, air screw (deck-mounted airplane type propeller), and submerged propeller. The bow-mounted submerged propeller has won out in the competition because it is more efficient than any of the other devices.

Several propeller mounting arrangements are possible (Fig. 1). In one, the propeller is retractable from the bow and when extended may be capable of rotating to provide thrust at various angles. Another has the propeller in a transverse tunnel below the water line.

Types of Drive

The prime mover for the propeller can be either a diesel engine or an electric motor. The electric motor is far more satisfactory because its short-time overload capability, and the intermittent service characteristic of bow-thruster operation, permits choice of a relatively small machine. Also, the electric motor is usually the least expensive drive, provided the electric power supply has adequate capacity for the additional load. This capacity has to include ability to supply current inrushes on starting and sudden application of full load, because these inrushes could cause excessive generator voltage dips. When necessary, reduced-voltage starters are applied.

The propeller used with either of the two general arrangements shown in Fig. 1 can be a fixed-pitch type or a controllable-pitch type. The two types have different characteristics, so a different drive and control is applied to each.

The fixed-pitch propeller provides thrust approximately in proportion to the propeller rpm squared. Therefore, the amount of thrust is determined by the speed of the propeller's prime mover. To control the rate of maneuvering the bow, the prime mover's speed must be controllable. Another characteristic of the fixed-pitch propeller is that its prime mover's direction of rotation ordinarily must be reversed to reverse the direction of thrust. (An exception is the type of bow thruster in which the entire propeller head can be rotated to change thrust direction.) For these reasons, the wound-rotor motor is the recommended prime mover for fixed-pitch propeller applications. The motor control consists of a five-speed-point reversing master switch in a watertight enclosure, a set of secondary resistors, and a control panel in a dripproof enclosure. Thrust is easily controlled from the ship's bridge by changing the motor's secondary resistance with the master switch.

In the controllable-pitch propeller, each blade is actuated by a hydraulic mechanism that rotates the root to change the blade's pitch. The blades are fastened inside the hub by a pin and crank, with seals between blade root and hub to keep water out of the hub. Thrust magnitude is varied, and thrust direction reversed, by changing the pitch of the blades. The requirement of the prime mover, then, is to provide relatively constant speed. The squirrel-cage motor is especially suited for this application because the propeller does not have to be reversed. The control equipment is simply a reduced-voltage autotransformer or reactor starter, with motor protective devices, in a dripproof enclosure. After starting, the motor runs essentially at constant speed, and thrust control is easily accomplished

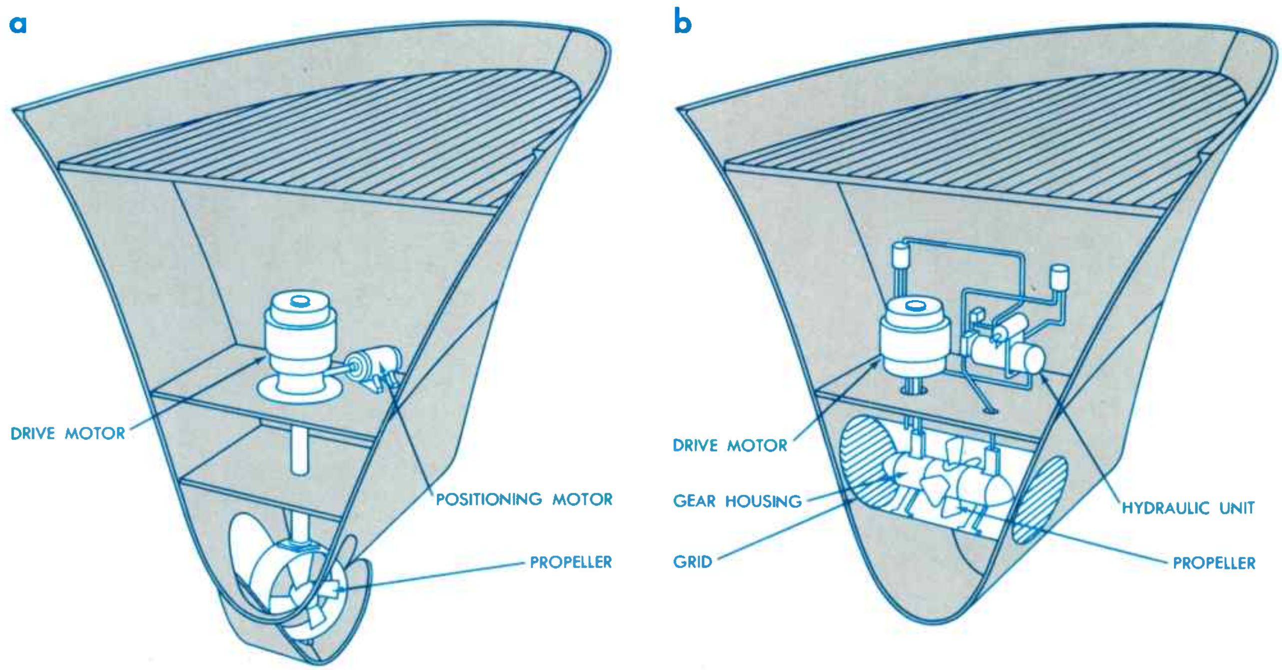


Fig. 1 The two basic bow-thruster propeller mounting arrangements are diagrammed here. (a) Propeller mounted on a shaft that is extended for use, retracted when not in use or when operating in shallow water. (b) Propeller mounted in a transverse tunnel below the water line. The one shown here has a variable-pitch propeller, hydraulically actuated, for varying the thrust magnitude and reversing the direction of thrust.

from the ship's bridge by hydraulic actuation of the propeller's pitch-changing mechanism.

Drive Considerations

The important application characteristics—such as ship's size, type of service, draft, and desired bow-swinging speed—are different for each ship. However, the bow-thruster load cycle (a repetitive pattern of load and speed requirements imposed on the prime mover) is similar in each case and can be used to determine the required motor rating and size for any application. This determination is made by balancing the load requirements against the capacity of the motor, with the capacity of the motor expressed as horsepower and rpm at a given temperature rise for a specified time. ("Short-time rating" is the term applied to machine capacity specified in this way.)

To determine a motor's capability and to check it against a load cycle, certain motor and load-cycle data must be known. The required motor data are the horsepower required by the application, type of insulation selected, and heating and cooling rates. Load-cycle data required are longest time at full load, shortest time at no load or zero pitch, and (for controllable-pitch propellers) motor load at zero pitch.

The horsepower required by the application is selected by the owner or naval architect on the basis of the desired bow speed (expressed as time required for swinging the bow 180 degrees). The determination of this horsepower is the starting point for the subsequent selection of the motor frame size.

The type of insulation used governs the allowable temperature rise. Insulation classes and their allowable rises are controlled by such regulatory agencies as the U. S. Coast Guard and the American Bureau of Shipping. Allowable temperature rise is a factor in selecting the motor frame size that provides the proper amount of temperature-time capacity.

Heating and cooling rates are characteristics of each motor frame size. After the frame size has been selected, these characteristics are used to determine if the machine has been properly applied.

The design requirement of desired time for swinging the bow 180 degrees is used as the value of longest time at full load. This time may be from 10 to 20 minutes, depending on the ship's size and the bow-thruster motor's horsepower. The system designer sometimes adds 10 or 15 minutes to this value to provide for unusual conditions such as strong winds or currents.

Shortest time at no load or zero pitch is harder to estimate but can be based on experience or observations. For example, experience with a similar ship with a bow thruster might be used as a guide. Evaluation of the most difficult port likely to be visited can provide an estimate of the amount of maneuvering required. The more maneuvering necessary, the shorter the off time will be. This time could run from 3 to 15 minutes.

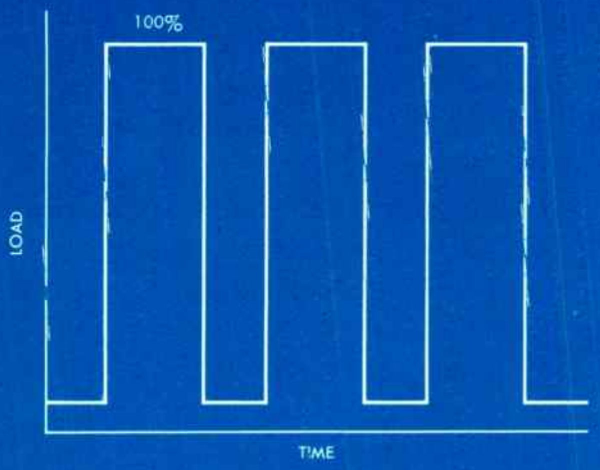


Fig. 2 To select the minimum size drive motor consistent with ability to handle all anticipated maneuvering situations, bow-thruster designers base the selection on the duty cycle diagrammed here. The duty cycle consists of a repetition of the longest anticipated time at full load and the shortest anticipated time at no load or zero propeller pitch.

The motor for a controllable-pitch propeller has some loading even during periods of zero pitch because of drive-train and propeller rotational losses. Motor load current during zero pitch is a factor in checking the frame size selected.

The load cycle pattern is established by the manner in which the bow-thruster operator applies thrust. All observations and tests to date indicate that the part-load positions are seldom used—full-load thrust is usually applied in an on-off manner. The load-time cycle, then, is composed essentially of two parts—time of full load and time of no load.

The values of operating time at full load and no load vary each time the bow thruster is operated, because they depend on the amount of maneuvering required. Although the values vary, it is fully possible to take advantage of the on-off nature of the loading to short-time-rate the drive motor. An effective method used by Westinghouse marine systems engineers is to base the motor rating on a duty cycle composed of the longest anticipated time at full load and the shortest anticipated time at no load or zero pitch (Fig. 2). These two times are determined in the manner discussed above.

To fit a motor to this duty cycle, the engineers choose a machine whose short-time rating corresponds to the anticipated longest time of full load. The machine reaches its rated temperature rise in this time; to do this repeatedly, it must cool each time to its temperature at the start of the cycle. The designers know the shortest anticipated time of no load or zero pitch, so they can calculate the motor temperature at the end of such a period to see if it does return to normal.

TYPICAL SHORT-TIME RATINGS WITH PERCENTAGES OF CONTINUOUSLY RATED LOAD

Time—minutes	Load—percent
120	130
60	135
30	150
15	175
5	200

Short-time ratings are possible because the time ratings are selected to be inversely proportional to loads, and both time and loading are tailored so that a machine's rise in temperature does not exceed a given limit. A machine of a given frame size can have different ratings for different types of loadings—for example, a short-time rating for one type of load and a continuous rating for another type. For a given frame size, the short-time rating, in horsepower, usually is larger than the continuous rating. The range of ratings for induction machines of 250 horsepower and larger with class A insulation, 55 degree C rise on a 40 degree C ambient, is indicated in the table.

Applying short-time ratings to bow-thruster motors permits selection of the motor frame size best suited to do the job. This results in the least expensive machine possible, since a short-time-rated motor usually is one or two frame sizes smaller than a motor of the same horsepower continuously rated. This rating method is applicable to both squirrel-cage motors and wound-rotor motors.

Motor Selection

The frame size is determined with information similar to that in the table, depending on the type of insulation used and the cooling characteristics. The system designer selects the value of short-time rating that is closest to the previously determined value of time at full load, and he reads the corresponding value of percent of continuously rated load. He then multiplies the previously determined horsepower required for the application by 100 and divides by the percent of continuously rated load picked from the table. The resulting figure is the horsepower rating required, and it determines the motor frame size.

To determine if this is the proper size, the machine's drop in temperature during the period of no load or zero pitch is calculated with the following equation:

$$T = T_o - (1 - e^{t/t_o})(T_o - T_u)$$

where T = temperature attained, absolute;
T_o = initial temperature, absolute;
T_u = ultimate temperature, absolute;
t = time over which machine is run, in minutes;
t_o = thermal time constant of the machine.

If the calculated temperature at the end of the cooling period is the same as the original temperature at the start of the cycle, the motor will operate satisfactorily and with normal life expectancy.

Thus, both types of bow thruster drive motor, regardless of variations in loading, can be selected to give the ship owner a drive tailored to his needs. This assures adequate capacity for the important bow-thruster duty while minimizing motor cost.

The Application of High-Voltage Power Fuses

Since the fuse is an economy and partially functional substitute for a circuit breaker, the fuse selected should be the economic choice having the most desirable characteristics that will do the job.

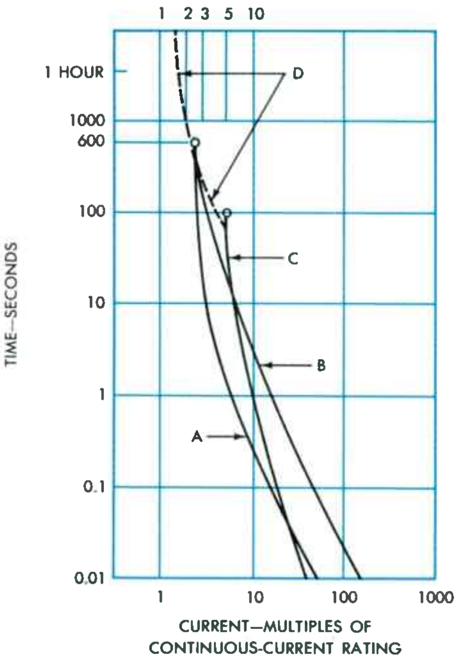
Frank L. Cameron
Assembled Switchgear and Devices Division
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

A wide selection of power fuses with a variety of characteristics has been designed to satisfy varying application requirements. No single type of fuse can cope with the full range of system voltages, continuous loads, and available fault currents. However, areas of overlap do exist between the various fuse types. In such cases, service requirements, physical and electrical clearances, and economic considerations may well govern fuse selection. As a rule of thumb, the power fuse with the interrupting rating that least exceeds the available fault current is usually the most economical choice.

Fuse Description

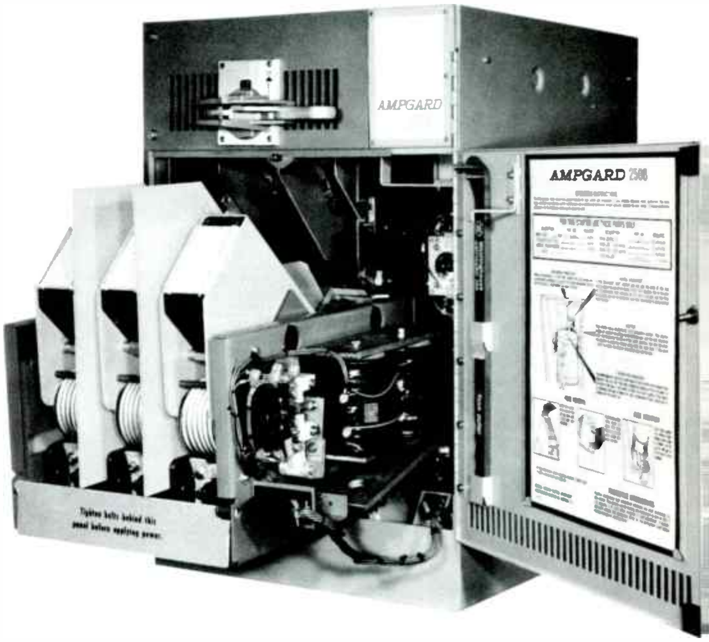
Fuses are selected on the basis of interrupting capability, continuous current ratings, and time-current melting characteristics. Melting characteristics are described chiefly by the minimum melting current and by the slope of the melting time-current curves, illustrated in Fig. 1. A ratio of approximately 2:1 between minimum melting current and continuous rated current takes cognizance of the inherent features of conventional fuses, and satisfies the average requirements of general-purpose high-voltage fuses. This ratio is expressed in the long established standard (NEMA SG2-20.13 of April 1960 and earlier issues) for general purpose high-voltage power fuses (E-rated) as follows:

a) The current-responsive element of a power fuse rated 100E amperes or below shall melt in 300 seconds at an rms current within the range of 200 to 240 percent of the continuous current rating.



A – Melting time-current characteristic of a fast (or standard speed) fuse rated 125-E or higher.
B – Melting time-current characteristic of a slow (or time-lag) fuse, rated 125-E or higher.
C – Melting time-current characteristic of a high overload current-limiting fuse.
D – Emergency overload limits at less than minimum melting current.

Fig. 1 Typical melting time-current characteristics and emergency overload limits of high-voltage power fuses.



The author wishes to acknowledge the writing and analytical work of Otto A. Ackerman, former Fellow Engineer, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania in his preparation of the fuse application data that served as the basis for this article.

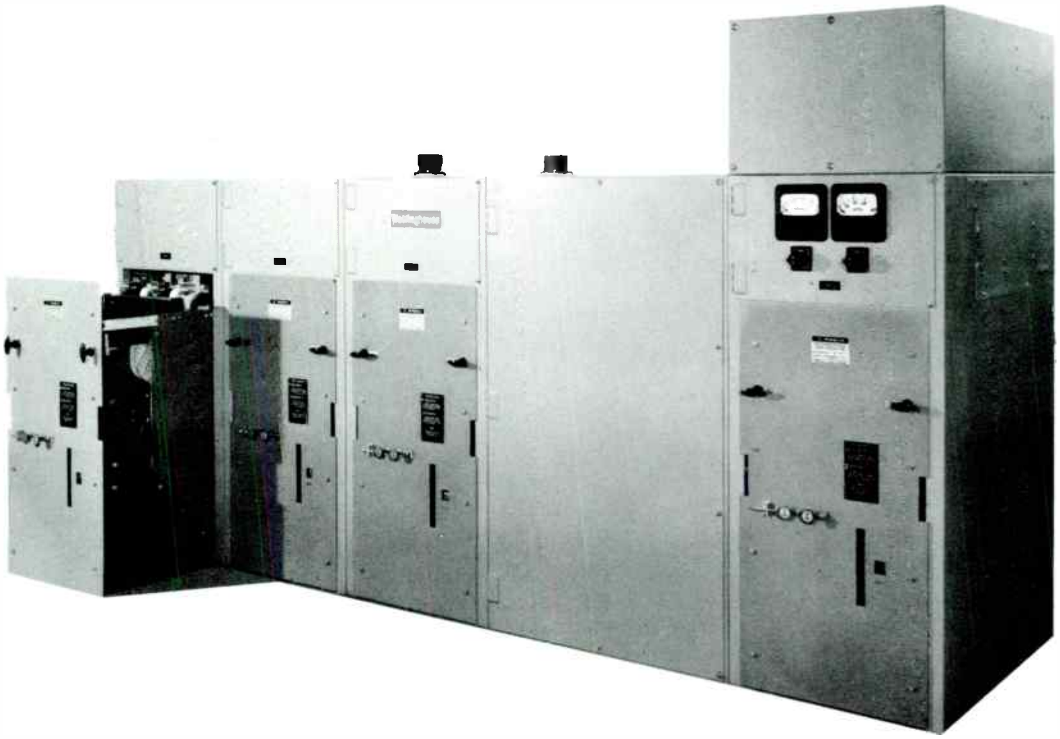


Fig. 3 Metal-enclosed 5-kv drawout fused switchgear consists of (right-to-left) incoming line unfused unit, power company metering compartment, and three fused feeder units.

b) The current-responsive element of a power fuse rated above 100E amperes shall melt in 600 seconds at an rms current within the range of 220 to 264 percent of the continuous current rating.

Typical melting time-current characteristics for high-voltage power fuses are illustrated in Fig. 1. The melting curves can be characterized as fast (or standard), and slow (or time-lag). The term *speed ratio* is used to define such curves more precisely. In accordance with Standard SG2-1.49, speed ratio is the ratio between the 0.1-second and the 300- or 600-second melting currents, whichever applies. A speed ratio of 19 is about the highest that can be obtained with a conventional type fuse. This tends to set a limit to the short-time (less than 300 seconds) overload-carrying ability of E-rated fuses.

When a higher short-time overload capacity is needed for a given continuous-current rating, it is necessary to depart from the conventional characteristics of E-rated fuses; this is especially true if high fault currents must also be limited. The above situation is most often encountered in motor-starter applications where high locked-rotor currents must be passed by the fuse without damage. Current-limiting fuses are especially favored for this type of protection. They have high interrupting ability and operate extremely fast to limit damage to motors, and protect starting equipment. A recently developed, extremely compact motor-starting equipment that uses current-limiting fuses to afford fault-current protection is shown in Fig. 2.

For most fuses, the published melting curves indicate long-time, low-current melting values (pivot point) that are near the lowest current at which the fuse will melt at all. Should currents below this minimum value, but substantially above the continuous rating, be applied for an excessive length of time, the fuse will be damaged and possibly made inoperative. The extent to which fuses may be overloaded below the melting range is usually specified by the individual manufacturer. A typical plot of overload limits is indicated by curve D in Fig. 1.

Fig. 2 This Ampgard 2500 medium-voltage fused starter has the following characteristics: 2200 to 2500 volts; motor capacity to 700 horsepower; air break contactor; interrupting capacity, 150 000 kva.

Fuse Selection

The first rule of fuse selection is that the maximum design voltage of the fuse must exceed the maximum line-to-line system voltage, regardless of system grounding conditions. The fuse voltage rating is permitted to exceed the system voltage by any desired amount except for limitations that apply to current-limiting fuses.

Current-limiting fuses perform their function by producing arc voltages that exceed the system voltage by a significant amount. These arc voltages must not be higher than the basic insulation level of the associated equipment, nor must they cause interconnected lightning arresters to operate since a relatively high current would be shunted into lightning arresters not designed for such interrupting duty. A properly designed current-limiting fuse limits the arc-voltage peak at rated interrupting current to something less than two times that of the nominal voltage rating. For example, the arc-voltage peak of a 4800-volt fuse would be $2 \times 4.8 \times 1.41 = 13.6$ kv. If short time application of this peak voltage is not harmful to associated equipment of a lower voltage class (say 2400-volt) apparatus, a 4800-volt fuse can be applied to the 2400-volt circuit.

The *interrupting rating* of power fuses is the rms symmetrical value (ac component) of the highest current that the fuse is able to interrupt under any condition of asymmetry. This is in accordance with a 1960 revision of the NEMA standards. Power fuses are not constant-kva devices. Identification with kva ratings for anything other than rough overall classification runs counter to the character of these devices, not only with regard to their operating principle but also in regard to the philosophy behind their application. Essentially, power fuses are employed instead of circuit breakers for reasons of economy. Once accepted, the economy principle should be carried to the point of ascertaining that the most economical fuse is used. This requires determination of the available fault current, which may well be lower than would be deduced from the rating of the nearest circuit breaker. A recently developed drawout-fuse-switch combination manufactured as an integral roll-out unit is shown in Fig. 3. Such a unit represents the ultimate in low cost, convenient protection.

Power fuses are designed to carry rated current continuously without exceeding the temperature rises permitted by the Standards. In the majority of applications, however, the current rating of the fuse should be greater than the rated load current of the protected equipment. Fuses have a rather low thermal capacity, and cannot carry overloads of the same magnitude and duration as motors and transformers of equal continuous-current rating.

If a circuit is to be protected by fuses, its normal load and the duration and frequency of permissable overloads should be determined. The fuse must then be selected to sustain these conditions, but blow at specified fault currents. These requirements would make each fuse application a case of special study if it were not for the routine procedures established for the protection of distribution and substation transformers with conventional E-rated fuses, and for fuses in motor starters.

Transformer Protection

As a matter of general application, the requirements for fuses on the primary side of transformers can be stated in order of their importance as follows. They should:

1) Protect the system against outages.

2) Protect against bolted secondary faults.

3) Override (coordinate with) protection on the low-voltage side.

4) Protect against higher impedance secondary faults to whatever extent is feasible.

In the routine process of selecting fuses on the basis of transformer kva rating, adequate secondary protection is assumed. Therefore, a standard-speed fuse is usually employed, rated to handle any inrush or overload current that the transformer permits and can carry safely. Such considerations dictate minimum ratios between fuse rating and transformer full-load current; and these minimum ratios are ordinarily a function of the fuse design.

Where provisions are made, by thermal relays or otherwise, to limit transformer overloads to a lower range, the fuse-to-load rating ratios can be reduced. It must, however, be remembered that:

a) Under no condition can the fuse current rating be less than continuous load current;

b) An E-rated fuse will not provide protection in the range between one and two times continuous load current.

c) With forced-cooled transformers, coordination must be based on the higher continuous-current rating.

For fuse coordination with secondary protection, a sufficient margin of safety must be provided to prevent melting of the primary fuse because, in service, the melting times are reduced below those shown in the standard characteristic by preloading and other variables. Usually, this margin is introduced into the coordinating procedure by lateral or perpendicular shifting of the no-load melting curve; the amount of shift is, to some extent, left to engineering judgment.

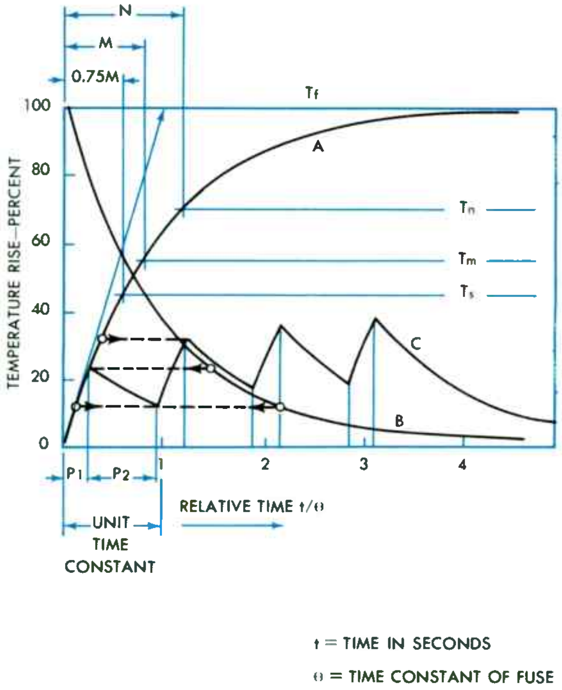
The upper limit of the current rating of the fuse is determined by the degree to which the transformer is to be protected by the fuse against faults on the secondary side. The line current seen by the fuse depends primarily on the nature of the fault and on transformer impedance. For routine applications, standard speed fuses can protect standard impedance delta-wye transformers, even against single-phase-to-neutral faults at the transformer secondary, if the fuse current rating is twice that of the transformer. For less critical cases, the fuse-to-load rating ratio can be considerably higher than 2:1.

Motor Protection

Since the continuous rated current of a fuse must be at least as high as that of the apparatus it is to protect, and, since the minimum melting current of the fuse is at least twice its rated current, a power fuse cannot protect an apparatus against anything less than 100-percent overload. Usually, this unprotected range or gap is even larger. If the user can forego protection in this range, a fuse can provide satisfactory protection at higher currents; however, certain additional restrictions are imposed by the fact that the damage characteristics of the apparatus and the clearing time-current characteristics of the fuse hardly ever coincide. Hence, fuse-protected apparatus may be exposed to overloads of somewhat longer duration than desirable, or the fuse may limit the equipment's overload capacity.

Full-range protection can be provided only by a combination of fuses and other sensing devices; for example, relays could be used to cover the range up to and somewhat beyond the maximum possible load current of the equipment; fuses would furnish only short-circuit protection. In this type of motor-protection scheme, the fuses are not protecting the motor itself but rather the circuit up to the motor terminals, particularly the starting equipment. In this type of application, the possibility of the fuse becoming affected by long-duration overloads (locked-rotor condition) should be avoided. This can be accomplished by selecting a fuse with a minimum melting current equal to, or in excess of, the locked-rotor current. Ten percent is a reasonable margin (where the manufacturer's application instructions will permit working this close), which means that the relay curve properly transposed into the fuse-melting characteristic should intersect the latter at a current ten percent or more in excess of the locked-rotor current. (Lacking specific information, the locked-rotor current may be assumed to be six times full-load current.)

The duty of fuses in motor-starter circuits is characterized by the frequent application of high overloads, i.e., motor starting currents. Properly designed motor-starter fuses are constructed to withstand these frequent and severe heating and cooling cycles without fatigue failures.



Curve A – Basic fuse heating curves: $T = T_f(1 - e^{-t/\theta})$

Curve B – Basic fuse cooling curve: $T = T_f \times e^{-t/\theta}$

Curve C – Temperature rise curve of fuse subjected to recloser cycle.

M – Melting time of fuse at a given fault current.

N – Total clearing time of fuse at same fault current.

T_m,T_n – Levels of melting temperature of fastest and of slowest fuse.*

T_s – Safe temperature level, considering service variables.

T_f – Hypothetical steady state temperature level (100%) attained if the fuse element does not open when melting temperature is reached but continues to be a resistance of constant value.

*The absolute temperature at which the elements of the fastest and of the slowest fuse melt is the same since both fuses are made of the same material. However, T_n and T_m are different if measured by the final temperature level T_f reached at a given current.

Fig. 4 Temperature cycle of fuse (curve C) during recloser operation.

Response of Fuses to Repetitive Faults

The performance of fuses under repetitive faults, such as produced by the operation of reclosing circuit breakers, must take into account the fuse heating and cooling characteristics. These characteristics are contained in and expressed by the melting time-current curves. For example, conventional (E-rated) fuses approximate bodies whose heating and cooling properties are described by the basic exponential curves *A* and *B*, shown in Fig. 4. Except for being inverted, the cooling curve is the same as the heating curve; both have the same time constant. Every fuse has a specific time constant, which is closely related to the speed ratio (S) previously defined. The time constant (θ) can be calculated with sufficient accuracy by the formula:

$$\theta = 0.1 \times S^2 \text{ (seconds)}$$

The time constant of a specific fuse, in terms of seconds, gives a specific time scale to the general heating and cooling curves of Fig. 4. The course of temperature (in percent values) can be plotted if the sequence and the duration of the open and closed periods of the recloser are known. This is illustrated by curve *C*, which is composed from sections of curves *A* and *B*.

To determine the temperature level at which the fuse will melt, melting time (M), obtained from the regular fuse characteristic for a given fault current, is entered into Fig. 4. The intersection of the ordinate to the time M with curve *A* gives the melting temperature (T_m). Its absolute value need not be known; it is sufficient to know its relation to the peaks of curve *C*. T_m marks the melting level of the fastest melting fuse of a given rating and design. This is in accordance with the standard definition of melting time-current characteristics. The level T_n where the slowest fuse of a certain group will melt is indicated by the total clearing time N applying to the same fault current. The total clearing time-current characteristic is actually the melting characteristic of the slowest fuse of a certain group, and the spread between the slowest and the fastest fuse is fixed in the Standard by the definition of E-ratings (200 to 240 percent, or 220 to 264 percent). In comparison to this tolerance, which allows for manufacturing variations, the arcing times that should be added to the melting period are insignificant. The intersection of curve *C* with T_n anywhere ahead of the last cycle signifies that the fuse can be relied upon to melt and clear before the recloser locks out.

Should the fuse be required not to blow, curve *C* must remain below the level T_m by a safe margin. This margin is usually provided by coordinating the breaker with a fuse curve whose time ordinates are 75 percent of those of the melting curve. Thus, the intersection of the ordinate to 0.75 M with curve *A* in Fig. 4 designates the safe temperature level T_s.

Conclusions

The basic rules governing fuse selection are observance of voltage rating, full-load rating, possible overloading, and the degree of protection required. Since fuses rather than circuit breakers are usually used for reasons of economy, consideration should be given to selection of the most economical type and rating of fuse for the task. Complete coordination with other protective devices requires that the thermal characteristics of fuses be studied and evaluated.

Technology in Progress

Plasma-Jet Radiation Source Produces Intense Beam

A new concept in radiative energy sources has been applied by scientists at the Westinghouse Research Laboratories in developing a powerful source of intense light. A high-pressure plasma-jet arc generates radiation that emerges from the self-contained unit through a quartz window in a converging beam. Collected radiant power is greater than has heretofore been possible with other continuous radiation sources.

The source consists of a stainless steel vessel designed for operation at high pressure—up to 600 pounds per square inch—for maximum emissivity of the plasma-arc discharge. (See photograph and illustration.) One half of the pressure vessel is a deep elliptical mirror that collects radiation from the arc and beams it through a quartz lens-window set into the other half. An inert gas flows continuously through the device, entering near the window and leaving as a plasma jet through a hole in the anode. The gas flow stabilizes the arc and also flushes out vapors to prevent mirror contamination. Both cathode and anode are water cooled. The cathode is made of tungsten and the anode either of copper or tungsten. Both electrodes can be adjusted for starting the arc and for regulating the length and position of the arc.

The plasma-jet radiation source has been operated at an input power of 15 kilowatts. At this power, the beam concentrates nearly five kilowatts of radiant energy on a spot about half an inch in diameter. Although operation has been restricted so far to power inputs up to 15 kilowatts, the source is designed for power inputs of 50 kilowatts or more. Tests indicate that units with inputs up to 100 kilowatts may be feasible.

The output of the radiation source is intense in the visible light spectrum and very rich in the ultraviolet region. Possible uses are in simulation of re-entry heating, high-intensity searchlights, laser pumping, arc imaging furnaces for melting metals and ceramics, solar simulation, catalyzing chemical reactions, welding, image projection, airport illumination, and advanced military applications.

Temperature and emissivity of the plasma arc are controlled by controlling the arc power and the chamber pressure. Radiation wavelength decreases as arc temperature increases, and spectral line widths increase with chamber pressure. Any inert gas or mixture of inert gases can be used, and the spectral distributions radiated are characteristic of the gas used.

■ ■ ■

Static Power Modules for Reliable Inverter Service

A modular "power cell" is the heart of a static adjustable-frequency inverter system being developed for industrial applications (see photograph). It contains the Trinistor controlled rectifiers, silicon diodes, and other static devices required to switch dc power on and off in such a way as to produce a three-phase ac output with the desired frequency and with constant volts per cycle. The switching is regulated by signals from a controllable master oscillator, and no complex feedback network is required.

Initial applications of the inverter will be in such operations as chemical fiber and glass fiber production, in which groups of motors must operate at exactly the same speed and with precise adjustable speed control through adjustment of power frequency. The inverter is a development of the Westinghouse General Control Division and will be a component of systems supplied by Westinghouse Industrial Systems.

A complete inverter will consist of a silicon-rectifier power supply, a control unit that includes plug-in logic firing boards and the master oscillator in a controlled atmosphere to assure constant stability, and the required number of power cells. The power cells are of plug-in design and can be removed from the cabinet quickly and easily. All power cells are identical in size and design.

The inverter rating is determined by the number of power cells, the controlled-rectifier rating, or both. Standard ratings will range initially from 30 kva to 500 kva at power factors from 30 percent to unity. Standard frequency range is 10 to 200 cps, with 6-to-1 maximum continuous adjustment, ±0.05 percent accuracy, and constant 2.0 or 4.0 volts per cycle over the entire frequency range. The precision oscillator maintains frequency stability in this range through ambient temperatures from 10 degrees C to 40 degrees C. System efficiency is 90 percent, and harmonic content of the output power is below 15 percent without filters on minimum load.

■ ■ ■

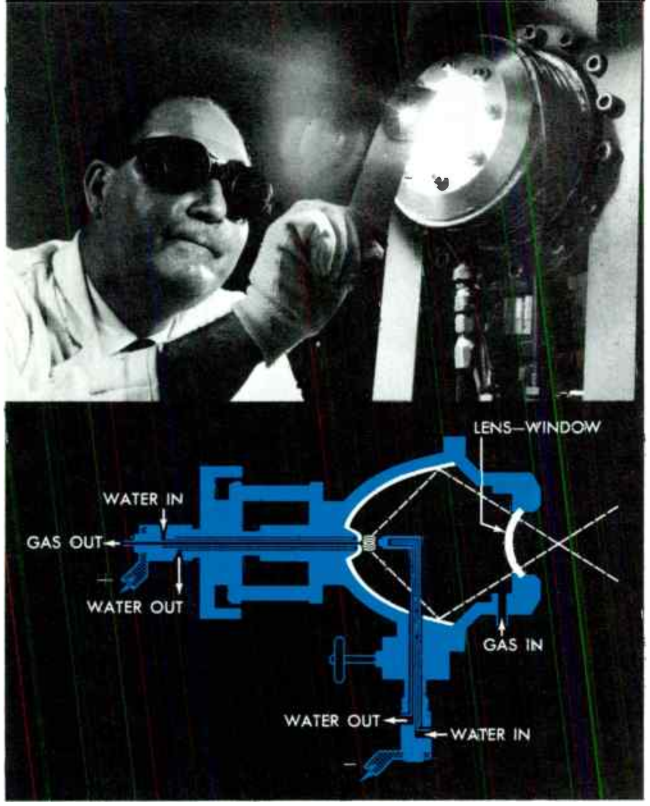
Rolling Mill Designed for Lightweight Tinplate

Quantity production of thin tinplate appears to be the most significant development of the early 1960's in the tinplate industry. The product enables can manufacturers to make more cans out of less steel. Its light weight also saves money in shipping both filled and unfilled cans; moreover, it encourages development of entirely new uses for tinplate.

The thin tinplate now being produced is approximately 0.006 inch thick, compared with a thickness of around 0.009 inch for most tinplate. As with most new materials, development of the thin tinplate has necessitated development in processing equipment. Initially, steel companies modified existing cold-rolling mills to perform the reduction from hot-rolled steel strip. Now, however, the first mill specifically designed for production of lightweight tinplate has gone into production at the Weirton Steel Company, Weirton, West Virginia, a division of National Steel Corporation.

The new mill is a two-stand tandem cold reduction mill designed and built by Mesta Machine Company. It has 19-inch work rolls and 56-inch backup rolls, and it processes 60 000-pound coils 45 inches wide at 5000 feet a minute. The mill takes steel strip that has been initially cold-reduced by another mill and continuously annealed. It reduces this strip to thin-tinplate gauge from the original cold-rolled thickness.

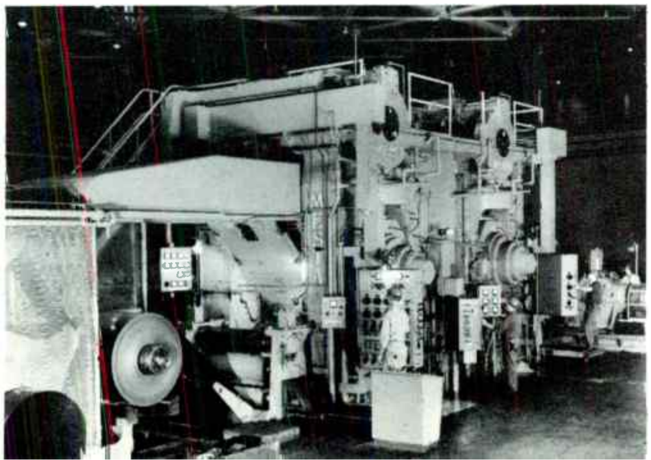
The entire electric drive and control system for the new mill was supplied by Westinghouse. Each main stand has



A 1/32-inch steel strip, held at the focus of the new radiation source, is burned through in less than four seconds by the extremely intense beam of light. The illustration shows the basic design of the radiation source and the general arrangement of its components.

This module contains the static switching components of a new adjustable-frequency inverter. Switching is regulated by a master oscillator.

This cold reduction mill was designed specifically for rolling lightweight tinplate. Its automatic gauge control system provides the close regulation of tension and screwdown needed for successful high-speed production of the thin steel strip.



two 2000-horsepower motors in a twin drive arrangement; total motor rating on the mill is 11 000 horsepower. Variable-voltage control is used, with the main drive motors and generators directly excited by Trinistor controlled-rectifier regulators.

Close control of product characteristics is provided by an automatic gauge control system, with all-static circuitry, actuated by signals from x-ray thickness gauges. The system has three modes of operation: control of screwdown setting on the first stand, control of tension between the stands, and control of tension between the feed reel and the first stand. These modes can be used independently or in combination, a feature that makes the mill unusually versatile. The operator selects the mode or combination of modes that best suits the material being rolled.

The mill also can be operated without automatic gauge control. In that mode, it is operated either completely manually or with automatic regulation for constant tension between the stands. ■ ■ ■

Computer Method Determines Energy Requirements Accurately

A digital computer program has been developed to determine the total amount of energy required of any type of conventional or new supply system to meet the heating, cooling, and electric requirements of a building in any climate. Analysis of the energy requirements provides cost figures which, combined with capital and operating costs, form the basis for a complete economic evaluation of the proposed energy system.

The new computer method was devised by Westinghouse Utility Systems Engineering to help building owners choose between purchased power and on-site power generation. It employs a mathematical model and simulation techniques. The model accounts for all factors affecting energy use—type of construction, inside environmental conditions, ventilation rates, outside ambient temperatures, building occupancy, and so on.

Hour-by-hour simulation of steam and electric loads is a new feature in this program. Hourly simulation is needed for really accurate prediction of energy needs because the loads change constantly. After the computer program has established the amount of energy required by the load, it simulates operation of the energy supply system to calculate the amount of fuel required. Hourly weather data obtained from the U. S. Weather Bureau is taken into account.

The final output of the program—annual energy cost—is based on prevailing local energy rates. Other factors considered include equipment ratings, local ordinances, type of utilization equipment, system operating methods, maintenance needs, reliability, space requirements, taxes, and insurance rates. ■ ■ ■

Thermoelectric Space Power System Stores Solar Energy for Later Use

A thermoelectric power system that uses both direct and stored solar energy is being developed to demonstrate the feasibility of the concept for advanced space vehicles. The initial model is a ground test unit capable of producing at least 10 watts of electric power. It is being built by the Westinghouse Aerospace Electrical Division for the Air

Force Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

The advantage of the heat-storage approach for an orbiting vehicle would be provision of heat for the thermoelectric element during the dark part of the orbit. Thus, no batteries would be needed for power supply during the dark part.

During the sunlit part of an orbit, solar energy would be directed by a parabolic reflector into a cavity in the thermoelectric generator. Some of the energy would be converted directly into electricity by the generator, and the surplus would heat lithium hydride lining the cavity. The lithium hydride would melt and store a large amount of heat. This heat would be given up to the generator at the required rate to produce electricity during the dark part of the orbit. ■ ■ ■

Largest All-Static Packaged Drive Operates Giant Cement Kiln

A 500-horsepower two-motor drive system supplied recently for a cement kiln is the largest packaged static adjustable-voltage drive installed so far. Saturable power reactors and silicon rectifiers replace the conventional motor-generator set, making the dc motors the only rotating parts in the drive system.

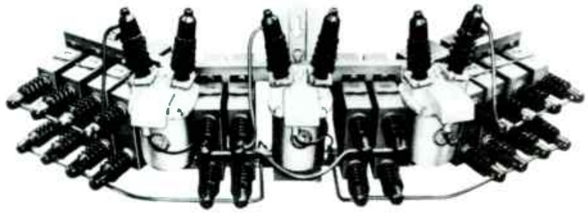
The drive will slowly turn a huge kiln (500 feet long and about 15 feet in diameter) in which raw materials are fired to produce cement clinker. The kiln will operate through a speed range of four to one—20 to 80 revolutions per hour—at constant torque. The pair of 250-horsepower shunt motors, with 240-volt armatures connected in series, will operate over this speed range by armature voltage control. Drive speed is regulated to one percent accuracy at the 1170-rpm top motor speed.

The Westinghouse Reactifier drive control system employs comparison of a tachometer feedback signal with a reference signal from a Zener diode. The resulting error signal is amplified by a Trinistor controlled-rectifier amplifier to control self-saturating power reactors that adjust motor armature voltage and thus regulate motor speed. A static ramp function generator with current limit control from zero to a preset speed provides for stepless acceleration of the motor.

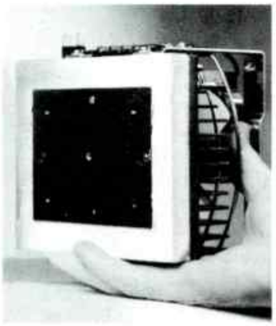
Remote instrumentation pickups and control equipment will permit operation and monitoring of the kiln drive at the cement plant's central control panel. The designers also provided for future control of the kiln drive with a master reference signal from a central plant control system.

The control equipment consists of a 5-kv line switch, an Ampguard high-voltage motor controller, a 750-kva 4160- to 480-volt ventilated dry type transformer, and the 500-horsepower Reactifier unit, all in a matching lineup of metal-enclosed cubicles. Power diodes are individually fused and have over capacity so that loss of a diode in each string of diodes will not shut down the drive system. Only a fault or a dangerous overtemperature could shut down the drive, and a warning signal would alert the operator well before overtemperature occurred. These protective features will provide the continuity of operation that is essential for profitable production of cement clinker.

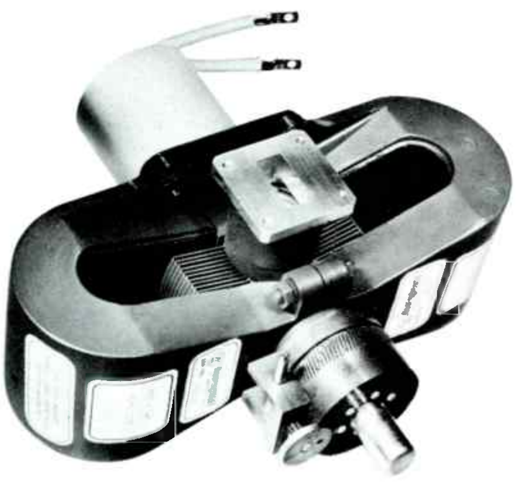
Products for Industry



DISTRIBUTION CAPACITOR ASSEMBLY for pole mounting is factory assembled, complete with oil switches. The "swept-wing" Autotrol can accommodate 25-, 50-, and 100-kvar units with no frame change. Junction box, switches, and capacitor units are accessible either from the pole or from an elevated basket.
Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa.



THERMOELECTRIC HEAT PUMPS with matched power supplies are assembled units ready for installation for spot temperature control. Five standard configurations provide a range of capacities. The units consist of a thermoelectric element, fin and fan combination, and cold plate.
Westinghouse Semiconductor Div., Youngwood, Pa.



HIGH-POWER MAGNETRON is intended for use as a pulsed oscillator in component testing but also has radar applications. Power output is 600 kilowatts at 0.5-microsecond pulse width and 400 kilowatts at 3-microsecond pulse width. Average power output is 400 watts, and the device is tunable over the frequency band of 8500 to 9600 megacycles.
Westinghouse Electronic Tube Division, P. O. Box 284, Elmira, N. Y.

about the authors

J. R. Jowett earned his bachelor of applied science degree in electrical engineering at the University of Toronto in 1949. He joined the Reliance Electric and Engineering Company, Canadian Division, and served in management positions in product design, application, and sales. He then was transferred to the Control Division in Cleveland, Ohio, as an engineering section manager responsible for process industry controls.

Jowett joined the Westinghouse Systems Control Division in 1960 to manage paper-industry systems sales and applications. The following year he was put in charge of a task force to study numerical control. He organized a new department in 1962 to handle engineering, application, sales, installation, and service for numerical control, and he became the first manager of this Numerical Control Product Line Department.

D.C. Cumming and **C.M. Knarr** combine theoretical interest and practical competence in two areas that had little in common until recently—manufacturing engineering and computer systems. They are largely responsible for development of the CAMP II computer system for numerical control programming.

Cumming graduated from Illinois Institute of Technology in 1951 with a BSME degree. He served in the U. S. Navy from 1951 to 1954 as a Lieutenant (J.G.) engineering and operations officer on a minesweeper. He then joined Westinghouse on the Graduate Student Course and was assigned to the Headquarters Manufacturing Laboratory to help develop automatic assembly machines. He moved to Headquarters Manufacturing Research in 1958 to work on computer applications in manufacturing. Early this year he became a staff assistant in Headquarters Manufacturing Planning, responsible for numerical control and equipment justification.

Knarr received his BS degree in secondary education, with a major in mathematics, from Indiana State College, Indiana, Pennsylvania, in 1953. He has since taken graduate work in mathematics and computer applications at the University of Pittsburgh and Carnegie Institute of Technology. He served as a radio officer in the U. S. Army Signal Corps from 1953 to 1955 and then taught ninth-grade science. Knarr joined Westinghouse on the Graduate Student Course in 1956 and worked on manufacturing research and advanced manufacturing concepts in Headquarters Manufacturing Planning. He is now responsible for automatic information handling in manufacturing.

Geo. F. Gayer came with Westinghouse on the Graduate Student Course in 1929, after graduating from Oregon State College (BSME). He was assigned to the Steam Division at South Philadelphia, where he first worked in the experimental laboratory. He shortly moved to the Marine Division as a design engineer, and later became a section engineer.

Gayer left Westinghouse for the shipyards in 1940, to serve as chief test engineer for a shipbuilding firm in the Seattle-Tacoma area. Gayer rejoined Westinghouse in 1947 as Engineering Manager of the Westinghouse Manufacturing and Repair plant at Sunnyvale.

Gayer was plant manager of the M & R plant when it was enlarged to the Sunnyvale Divisions, and he assumed his present position of Division Engineering Manager for the Sunnyvale Divisions.

Both **Dr. E. L. Harder** and **C. J. Baldwin** have previously appeared on these pages to discuss computers.

Since Harder's last appearance, when he was Consulting Engineer and Director of the Analytical Department, he has been assigned staff responsibility for the application of computers in engineering throughout Westinghouse. In 1961, he was assigned responsibility for advanced systems engineering of apparatus products. In the recent province realignment, the Advanced Systems Engineering and Analysis Department, of which he is manager, became a part of the Electric Utility Province organization. It continues to operate the central engineering computer facilities for the company and carries out advanced system engineering for the Electric Utility Province.

Harder is a graduate of Cornell University (BSEE), and obtained his PhD in mathematics and engineering from the University of Pittsburgh.

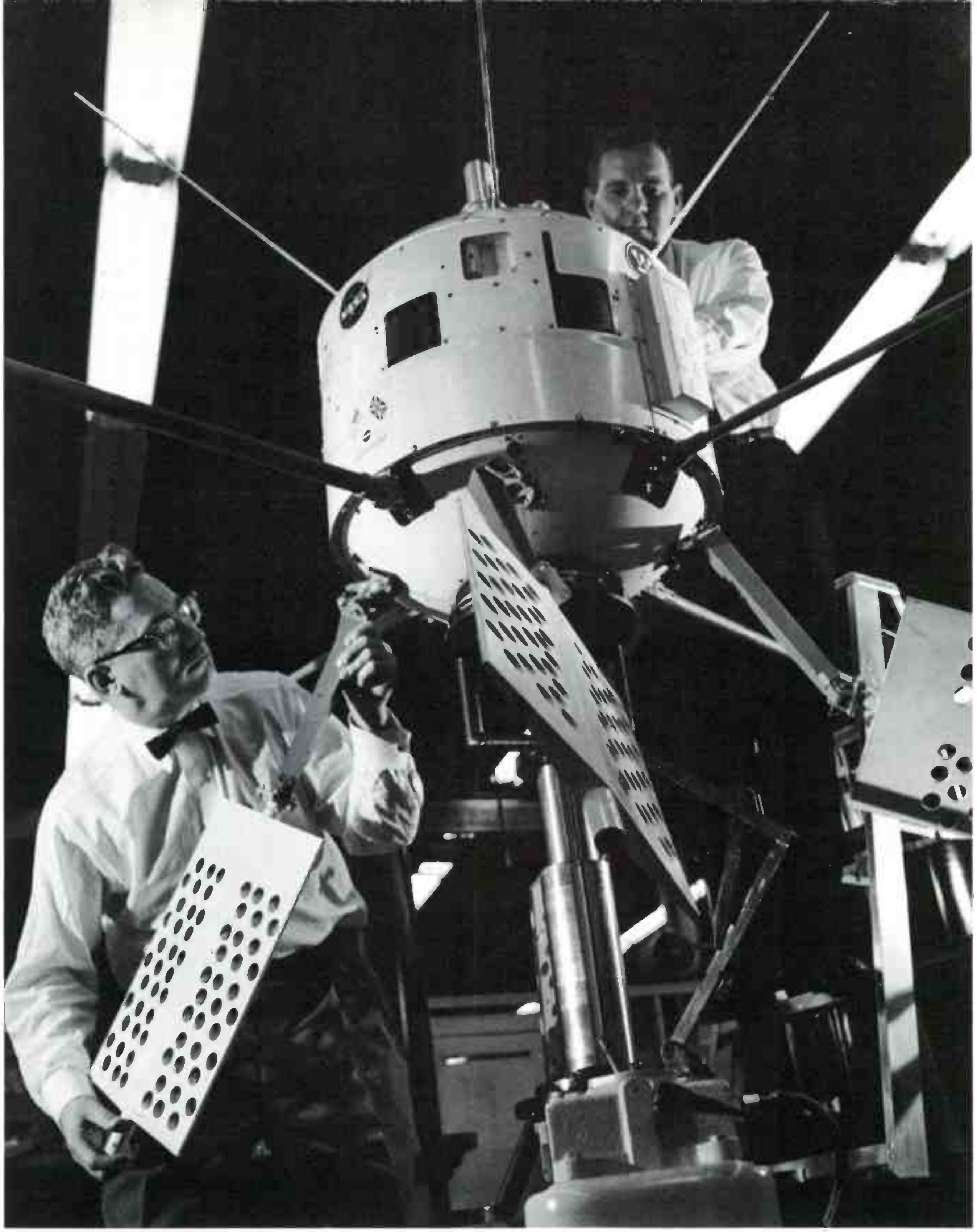
Shortly after his last appearance in the magazine, Baldwin was selected the Outstanding Young Electrical Engineer in the nation by Eta Kappa Nu, the electrical engineering honor society. A key contributing factor to his selection was his outstanding work in developing power system simulation techniques.

In 1962, Baldwin was appointed manager of the generation section of the Electric Utility Engineering Department. In addition to system planning studies, he is also responsible for power system control investigations, auxiliary systems for power plants, and studies of new power generation sources.

Baldwin is a graduate of the University of Texas (MS in EE), and holds a professional EE degree from MIT.

J. L. Pinson is an application engineer in the Marine Systems Department, where he applies modern drive and control techniques to ships' bow thrusters and other marine drive systems. He graduated from Lamar State Technical College, Beaumont, Texas in 1956 with a BS in mechanical engineering. He came with Westinghouse on the Graduate Student Course in the same year and, since then, has taken graduate work in mathematics at Carnegie Institute of Technology.

Frank L. Cameron graduated from the University of Wisconsin in 1951 with a BSEE, and came immediately with Westinghouse on the Graduate Student Course. His first assignment was with the Switchgear Distribution Apparatus Department, where he worked on the design and development of oil switches, reclosers, and fuse cutouts. In 1957, he moved to the Assembled Switchgear and Devices Department to concentrate on the development of power fuses. Here he has worked with motor starting fuses and transformer protection fuses, the application of which he discusses in this issue.



This engineering test model of the S-52 satellite structure, shown during construction, is being built by Westinghouse for the National Aeronautics and Space Administration. S-52, a joint U.S.-United Kingdom project, will measure galactic "noise," or the radio frequency signals generated by stars and galaxies; the distribution of ozone in the atmosphere; and the quantity and size of micrometeoroids in space. British scientists will provide the instrumentation for the satellite. Following this model, two prototypes and two flight models will be built before S-52 is launched. The project is managed and technically supervised by NASA's Goddard Space Flight Center, Greenbelt, Maryland.