Computer programming can make or mar control system

When specifying a computer-control installation, an important consideration is to insure that hardware and software are complementary. Inclusion of certain hardware features may save much work when programming the computer. Conversely, their absence may render certain instructions impossible to program. By properly weighing the cost of hardware against likely future programming requirements, proper balance can be established between the two sets of costs.

For example, in a situation where large memory capability is required, most economical solution is often to supplement the expensive high-speed "working" memory with a lower-cost auxiliary memory. This combines the advantage of high-speed arithmetical operations with relatively low overall memory cost. Typically, working memory would be magnetic core, and the auxiliary memory either disk, drum or magnetic tape.

Anticipate future expansion

Future needs must be forecast as accurately as possible when specifying a computer system. In many early process-computer installations, programming costs were extremely high because of hardware limitations. Memory was often too small, arithmetical operation slow, and input/output capability limited. Today's computer hardware has helped reduce programming costs considerably, but program changes and possible future expansion should still be taken into account before finalizing design.

In process-control work certain aspects of programming warrant extra consideration. These include real-time operation, memory capability and operator misuse. As a process computer functions in a real-time environment, a certain amount of "free" time must be available to allow for emergency reactions and special operator requests. A good rule of thumb is to allow 40% of free time within the computer; any less may cause the computer program to fall out of step with the operating situation.

Choose memory system with care

Memory capability, as mentioned previously, needs careful balance between working and auxiliary store capacity. System employing fast-working memory, supplemented by large but slow bulk storage memory, is economic compromise but presents problem of data transfer from one to the other. In such a system care must be taken in deciding which functions should remain in working memory at all times and which should be called in from store, as required.

Choice of program language is limited in practice to three: COBOL, ALGOL and FORTRAN. The first, Common Business-Oriented Language, was developed largely as a means of communicating computer functions in the field of business data processing.

ALGOL (Algorithmic Language) is a symbolic language independent of the particular computer structure. A program written in ALGOL is sufficiently legible for a programmer to read visually, yet, at the same time, may be translated automatically into any particular machine code by a suitable translator program.

Most process-control computers today use one of the variants of IBM's original FORTRAN. Prior to this, writing commands for a computer was a manual process. FORTRAN is, in fact, a compiler or program generator which produces a program automatically suited to the computer in use. Disadvantage is that any compiler-produced program requires about double the space needed by a carefully hand-written program. Thus, a boiler/turbine startup program can be written by hand in some 2000 words but takes 4000 words when produced by a compiler. FORTRAN finds principal applications in relatively infrequent procedures, such as plant startup and shutdown. Minute-by-minute scanning, on the other hand, is handled by a standard "scan, monitor and alarm" program filled in manually for the particular scanning sequence dictated by operating requirements.

Check validity of input signals

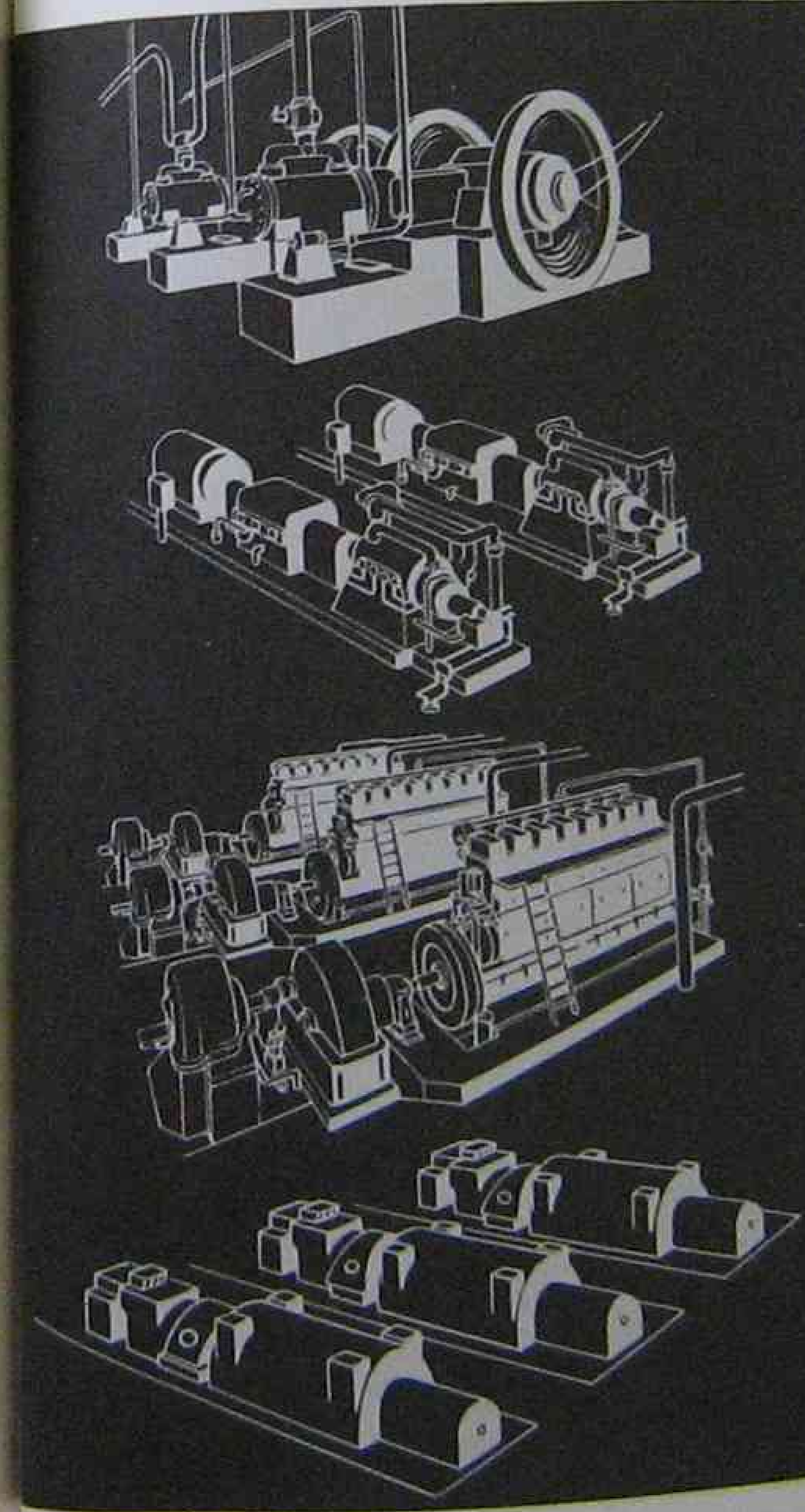
Self-checking program is important feature of process-control computer system. Unlike a scientific program in which the results obtained are printed out for perusal by an engineer, closed-loop control system utilizes the computer's calculations to act directly on the process plant itself. Should either input to the computer or data-handling within it be in error, the resulting calculated control points and output signals will be incorrect and could result in hazardous operation. Double and triple checks may be necessary to insure that operating data is valid. As more and more input signals are utilized, the programming necessary to provide such validity checks becomes increasingly more complicated. Continuous calculation of, say, heat balance can be useful in determining the validity of input information, since an extensive range of input data figures in the calculation.

Knowing the process itself is an important attribute of the system programmer. He can observe the overall relationship between program and process more easily, to establish the optimum frequency of data-logging, for example. Also, he can incorporate such aids to efficiency as fixed-point programming where this will speed up a repetitive loop function. For this reason, the present tendency among users is to train their own engineers as programmers rather than rely entirely on the computer manufacturer. To this end manufacturers provide comprehensive training courses—the Westinghouse Computer Center, for example, includes a self-contained school where customers' personnel may spend up to a year studying programming techniques.

Utilities, in particular, have found it essential that programmers be completely familiar with the power plant and its operation. Most of them now assign temporary potential programmers to the manufacturers' works, both to study and also to assist the manufacturers' own staff in an advisory capacity as problems arise.

By B G A SKROTZKI, Associate Editor

Energy system economics...



getting the most energy for the fewest dollars

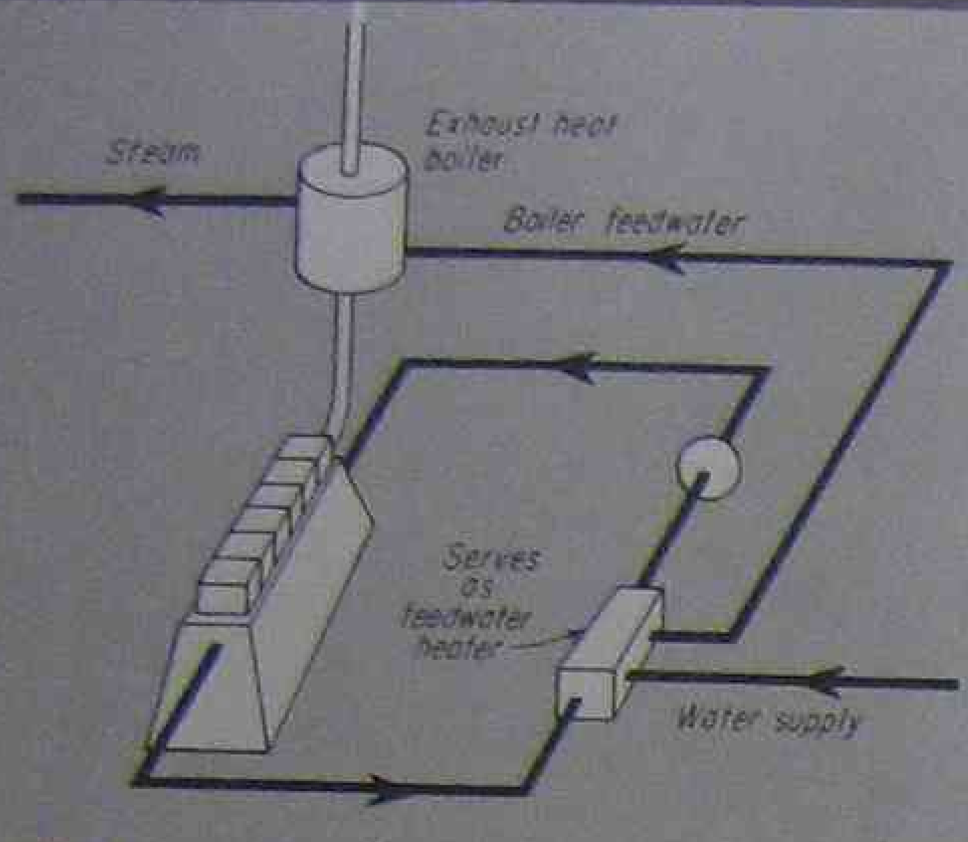
How are your dollars best spent to meet your growing energy demands? There's a wide variety of equipment and hookups available today, and you want to select the best for your system, whether it be central refrigeration, steam supply, fluid handling, compressed gas, chilled water or electric power.

With all investment and operating-cost data in hand, how do you go about choosing the best system? Here you must apply principles of engineering economics to the special problems of energy supply.

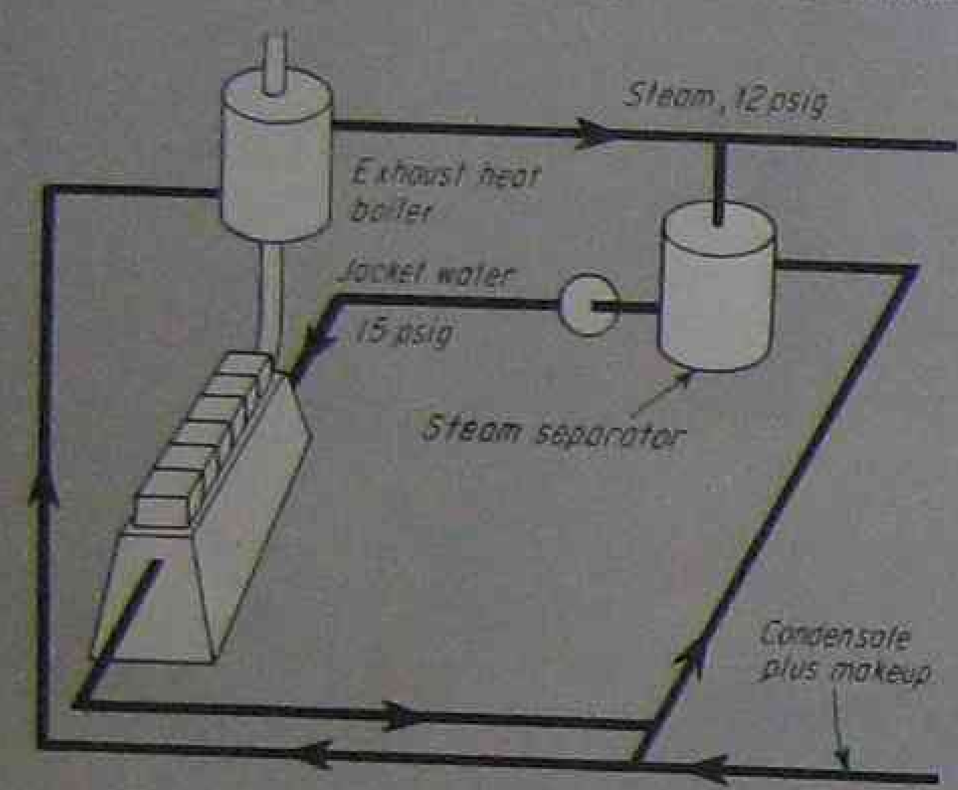
The energy systems handle media of radically different character, but for financial operating comparisons they are evaluated by essentially the same methods. We've picked electric power generation to illustrate the practical use of energy-system economics. These 24 pages show how to evaluate electric energy systems, but you can translate these methods to other energy-carrying systems by substituting lb per hr, cfm, Btu per hr, gpm or any measure used in other systems for kw and kwhr. Your aim: find the arrangement that promises lowest total annual cost of operation and capital charges. This will be one of the important factors in making the final choice of system layout.

Once your energy system is built, do you run it for best economy? To do this you must know your incremental costs. "Doing it by ear" on the basis of average performance curves only wastes fuel or energy if you don't know the actual cost of every energy unit. Here POWER shows the importance of the incremental rate in scheduling your equipment operation for best overall plant performance.

a Power special report • December 1961

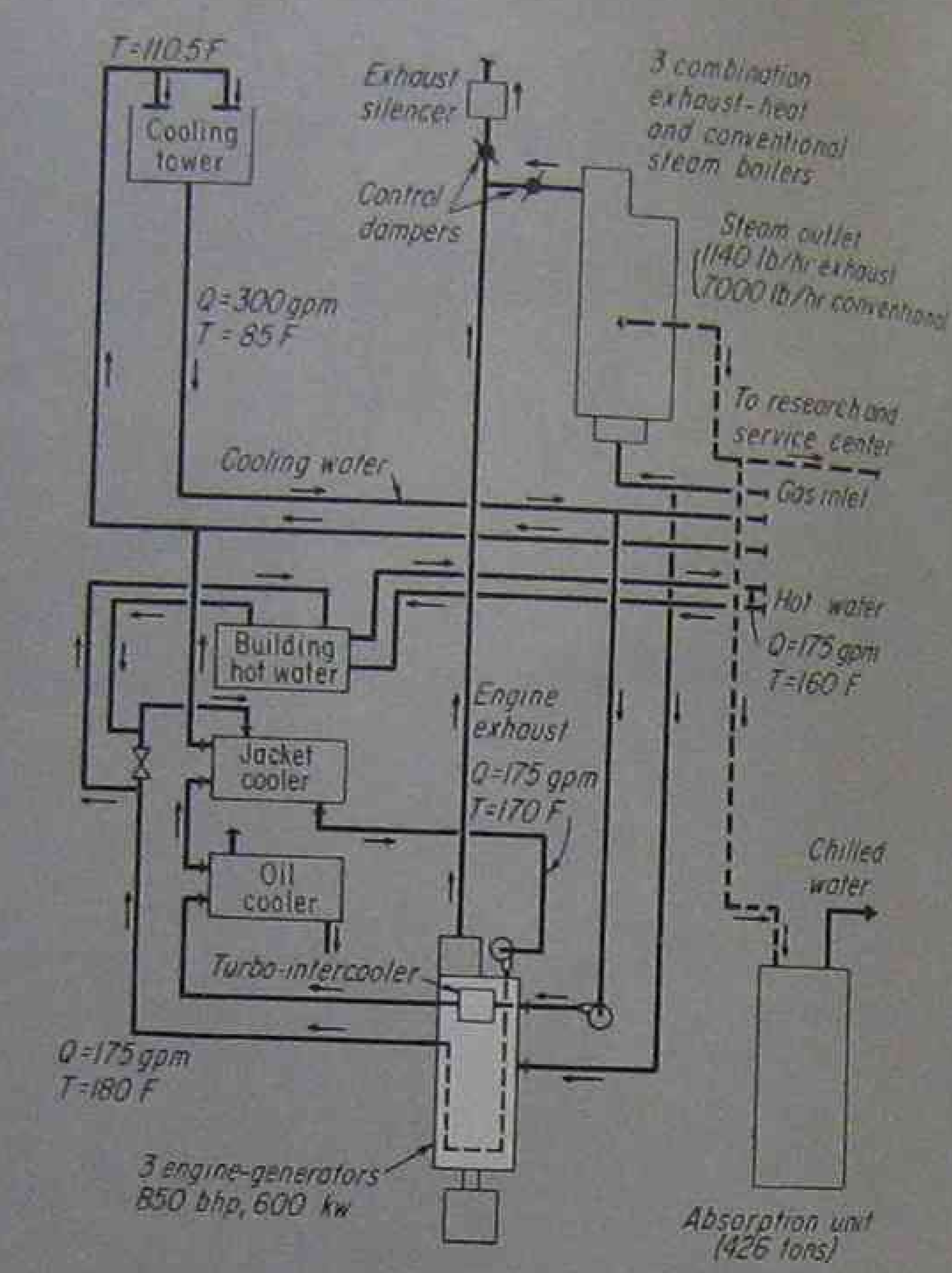


LOW PRESSURE STEAM may be generated in an exhaust-heat boiler, with jacket-water exchanger serving to heat boiler feedwater



VAPOR-PHASE SYSTEM generates steam. Higher and more uniform jacket temperatures help reduce corrosive cylinder wear

One way to use recovered engine heat



TOTAL-ENERGY CONCEPT is applied here through utilization of jacket and exhaust heat for hot water and building heating, cooling

include lubricating oil, operating labor, maintenance and repairs and fixed charges. Because data in this area was hard to come by, the Oil and Gas Engine Power Costs Subcommittee of ASME has published for many years an annual report giving actual cost experience of typical installations. The latest such report presents data collected from 95 plant operators throughout the U.S. for the year 1962. The subcommittee aims at fact finding and makes no attempt to establish conclusions or interpret the facts.

Applications. Oil and gas engines see service in the generation of electric power in municipal and privately owned stations and in industrial plants. Many find use as direct drives for pumps, compressors and other machinery in industrial plants, pipeline stations, etc.

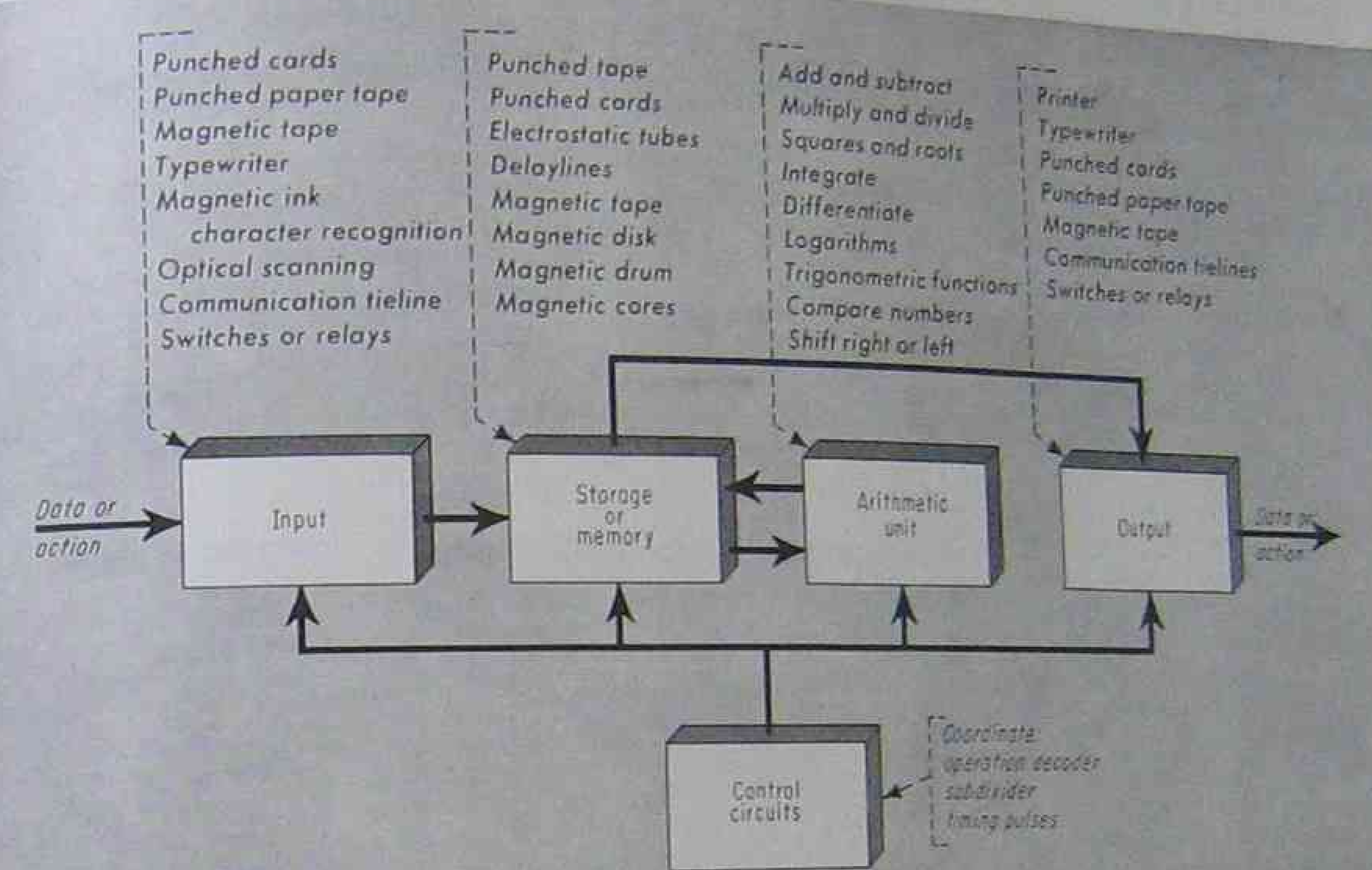
As peaking units on electric utility systems, the inherent compactness and flexibility of oil and gas engines permits locating them in key load center areas, aiding the development of a planned, economical system growth.

Engines continue to serve needs for standby power in industrial, commercial, institutional and military installations. In recent years, critical demands of some electronic equipment—microwave and computer installations for example—have led to increased interest in engine-generator sets able to take over with essentially no loss in electrical wave shape, frequency or voltage. Standby equipment of this kind has proved a practical answer to problems posed by electrical transients from switching, system faults, start-up of major in-plant equipment, lightning strikes, etc.

Heat recovery in engine installations has taken on added significance in recent years. Need for process and space heating has always presented an opportunity to recover some of the 60% or more of fuel energy not converted to brake hp. Sketches above and on preceding page outline some typical heat-recovery hookups.

Total energy concept is simply the application of oil or gas engines (or steam or gas turbines) to drive electric generators, with byproduct heat serving climate-control or plant-process needs. A strong factor favoring total-energy installations is the growth in year-around climate control. This, plus gas utility incentives makes many shopping centers, housing developments, commercial buildings and industrial plants prospects for total energy.

By B G A SKROTZKI, Associate Editor



1 Digital computers made up of thousands of elements have them grouped in five major sections. Input group loads the computer with data and instructions; memory stores the data; control circuits carry out instructions; arithmetic unit works with memory to carry out computations or comparisons under direction of the control circuits; output records answers or initiates actions

Automatic computer control: a time of trial

- Generating stations were probably the first to use automatic open- and closed-loop control systems
- Continued development of analog and digital computers point the way to achieving a fully automatic pushbutton energy-process control system and generating plant
- First approaches to automatic energy control superpose computers on more conventional intraplant control loops
- Ultimate automatic system is visualized as less complex control layout with both energy system and controls designed as compatible overall unit
- Unexpected problems and rising costs tax the control-designer's ingenuity to prove the computer in automatic control systems

Increasing use of arithmetic and its descendant, mathematics, and the growing mountain of data to be processed led man to develop easier ways of doing the job. So were born the abacus, the adding machine, the slide rule, the calculator. These relieved man of the boring chore of repetitive figuring, sped up the process and proved more accurate.

Analog computers. In the 1920's efforts were made to speed up the processes of more complex mathematics by putting electrons to work. Various electrical networks of resistances, inductances and capacitances and applying voltages at input terminals provided answers to complex equations by measuring voltages and currents at output terminals. The facility of this approach was expanded by developing various electromechanical and mechanical elements, Fig. 2, and answers could be produced in graphical form. In energy control systems this type of computer is called the special-purpose analog computer.

It does a wide variety of jobs by instantaneously figuring boiler efficiency, heat-transfer rates, mass flows, compressor efficiency, power demand, pump efficiency, viscosity, pressures, temperatures and liquid levels. Many of our familiar energy-system instruments can be classed as analog computers. For example, a flowmeter basically measures the pressure drop of a fluid passing through an orifice and by mechanical cams or by electrical resistance across a mercury manometer "computes" the flow and draws a line on a flow-vs-time graphical chart.

Analog computers and instruments have the virtue of being fast and relatively inexpensive. Generally they are special-purpose devices designed for one specific application. They are precision limited, the highest usually being on the order of one part in 10,000. With time, instrument accuracy may drift, and the computer may need periodic calibration. All analog computers are not necessarily electrical; some use hydraulic, pneumatic or mechanical components exclusively. This depends on the application and economics involved.

Analog computers often have hardware components not too different from conventional energy-system instrumentation. This means that generally no new maintenance skills need be developed. Also being less complex they are usually less expensive than digital computers.

Digital computers, Fig. 1, were born in the 1940's. They were another electronic approach to the high-speed processing of mountains of data with complex equations. The first ones used electrical relays or vacuum tubes to apply the very simple system of recognizing two states of an object: go or no-go, yes or no, true or false, 0 or 1.

The last-mentioned two alternative states are the basic tools of binary arithmetic, a counting system based on the number 2. The one we ordinarily use is the decimal system based on the number 10. Our decimal system is largely an arbitrary form of counting, probably derived from the fact that we have ten fingers, our handiest counters. Table 1 shows how binary and decimal counting systems correlate with each other.

The digits in a decimal number are the coefficients of the various powers of 10, the base of the decimal system. For example, the number 876 really means $8 \times 10^2 + 7 \times 10^1 + 6 \times 10^0$. The placement of each digit in the number tells how many hundreds, how many tens and how many units are in the total.

The binary system follows an analogous arrangement, each digit (which can only be 0 or 1) tells how many of each power of 2 is in the total. Thus the binary number 1010 means $1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$. Since most of us are strangers to binary arithmetic the number gives us no "feel" for the total value. Translating this into decimal arithmetic (see table) we find $(1010)_2 = (1 \times 8 + 0 \times 4 + 1 \times 2 + 0 \times 1)_{10} = (10)_{10}$.

This seems a cumbersome method of expressing numbers, but limiting the digits to 0 and 1 is the key to high-speed data processing. Computers designed in early days to handle decimal digits (0 to 9) always proved ponderous in size and slow in operation. Fortunately, in the modern digital computer, data can be fed in in decimal form, but the computer automatically converts this to binary, does binary arithmetic, and converts the answer to decimal form before discharging it as the result or output.

Each binary digit is called a "bit" in computer technology and the design and size of the machine depends on the number of bits it can handle in any one operation. In a computer, a bit can be represented by an electrical pulse or the absence of a pulse. The pulse can be a momentary voltage or current of very short duration, on the order of microseconds.

Pulses in a computer circuit: (1) establish basic timing (2) indicate information (3) control sequence of operations. A timing oscillator generates the basic pulses that control the sequential and repetitive operations through the control circuits.

The pulses representing bits in turn may represent characters which are numbers, letters or symbols, according to the code and combinations established for the computer.

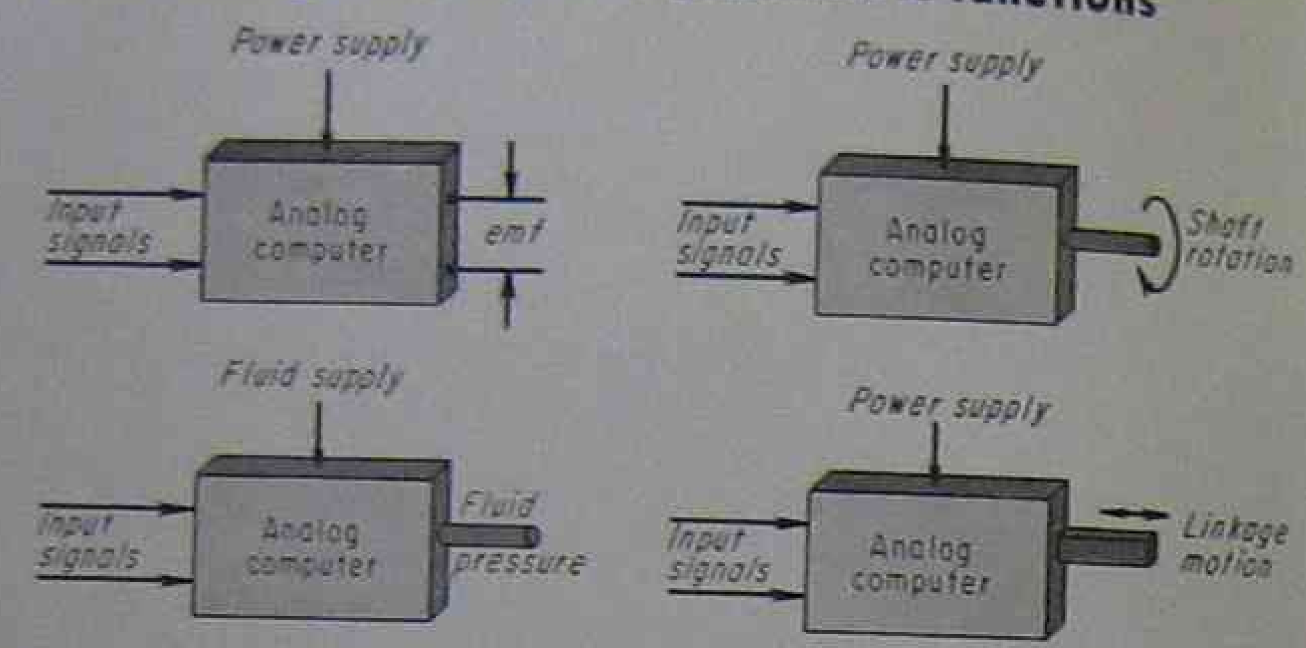
Grouping characters forms "words" that are the working form of the data processed by the computer. For instance, computers may have binary-coded decimals that use 4-bit groups to handle the range of digits from 0 to 9. To handle the alphabetic characters (26) they use 6-bit groups. A computer designed to work with a maximum of 48 bits per word can then handle $48/4 = 12$-digit decimal numbers or $48/6 = 8$-letter alphabetic words.

Computer layout. Fig. 1 shows the essential divisions of a digital computer and lists the type of equipment involved or the duties performed. The input section receives the basic data to be worked with and the instructions of what's to be done with the data. During the receiving process it converts the data to binary form. The memory receives the binary form of both data and instructions and as the list shows may use a wide variety of devices. Location of data in a memory is given by an address. Magnetic cores give a limited memory capacity but highest access speeds. On the other hand, magnetic tapes have highest capacity but low-speed access. Punched cards have the lowest access speed of all the devices.

The *arithmetic unit* consists of adders, registers, complementers and transfer networks. They may operate with pulses given in series through one circuit or by several circuits in parallel, usually the latter. Fig. 1 lists the functions that can be done by this division of a computer, by working in conjunction with the memory. In most computers after the results have been worked out in the arithmetic unit they are transferred to the memory for storage and eventual output.

The *control circuits* have elements known as program counter, ring counter, control gates, instruction and address registers and others. The power input, basic-timing-pulse generator and miscellaneous control signal elements are other important parts of the control circuits. The control circuit puts the computer through three instruction steps that are repeated continuously until all data is

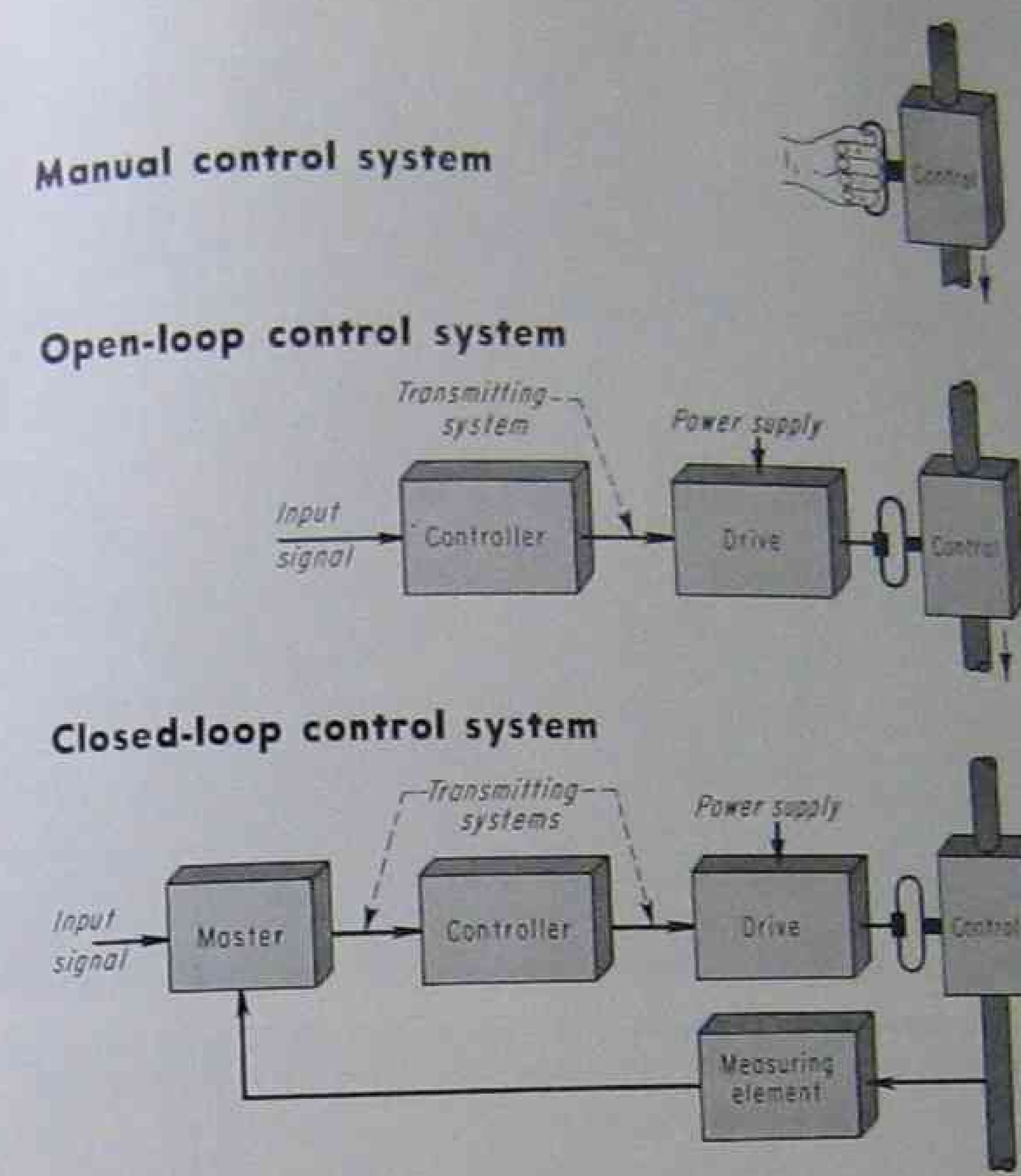
Analog computer controls add, subtract, multiply, divide, generate logarithms and trigonometric functions



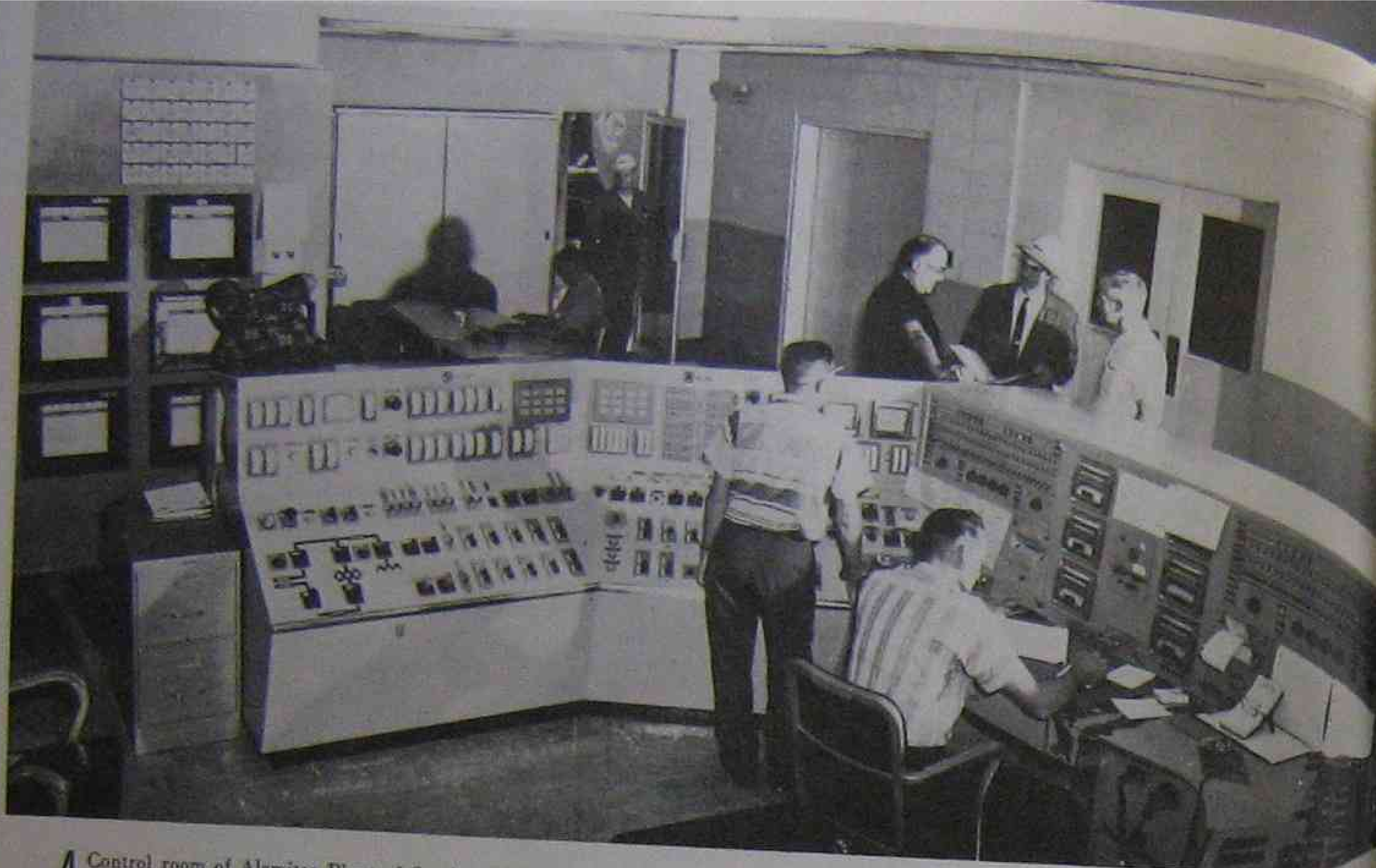
2 Analog computers were the first type of electronic calculators developed. Their variety of elements finds special applications in closed-loop energy control systems

1—Comparison of number systems

DECIMAL SYSTEM						BINARY SYSTEM					
	Weights					Weights					
Powers of base	10^3	10^2	10^1	10^0	Decimal number	2^3	2^2	2^1	2^0	Equivalent no.	
Decimal value	1000	100	10	1		8	4	2	1	Binary	Decimal
	0	0	0	0	0	0	0	0	0	0000	0
	0	0	0	1	1	0	0	0	1	0001	1
	0	0	0	2	2	0	0	1	0	0010	2
	0	0	0	3	3	0	0	1	1	0011	3
	0	0	0	4	4	0	1	0	0	0100	4
	0	0	0	5	5	0	1	0	1	0101	5
	0	0	0	6	6	0	1	1	0	0110	6
	0	0	0	7	7	0	1	1	1	0111	7
	0	0	0	8	8	1	0	0	0	1000	8
	0	0	0	9	9	1	0	0	1	1001	9
	0	0	1	0	10	1	0	1	0	1010	10
	0	1	0	0	100	1	0	1	1	1011	11
	0	8	7	6	876	1	1	0	0	1100	12
	3	5	7	9	3579	1	1	0	1	1101	13
	8	7	5	3	8753	1	1	1	0	1110	14
	9	9	9	9	9999	1	1	1	1	1111	15



3 Operator sets control to change the flow in manual control system. Open-loop control system holds control at set point. Closed-loop system compares actual flow with master input signal to hold flow or variable at the needed level through control



4 Control room of Alamitos Plant of Southern California Edison Co holds computer for supervising its Units 3 and 4. These are General Electric 325-mw 3600/1800 rpm turbine generators using 2400-psi 1050/1000 F steam from Combustion Engineering boiler

processed: (1) selection (2) evaluation or decoding (3) execution.

Computer *output section* equipment takes much the same forms as the input section. For the record type of output the binary-form signals from the memory are first converted to decimal or alphabetic form, though they may be stored in binary form on magnetic or punched paper tapes. When the computer acts as a control circuit, the binary-form signals from memory are first converted to analog form to work the controls of the governed system.

Operation of a computer is governed by the *programing* prepared for it. This is a skill that demands an intimate knowledge of both the computer's capabilities and all aspects of the problem to be investigated or the process to be controlled. Programing is a time-consuming function. When prepared for automatic process control, the cost of programing can easily equal the first cost of the computer hardware.

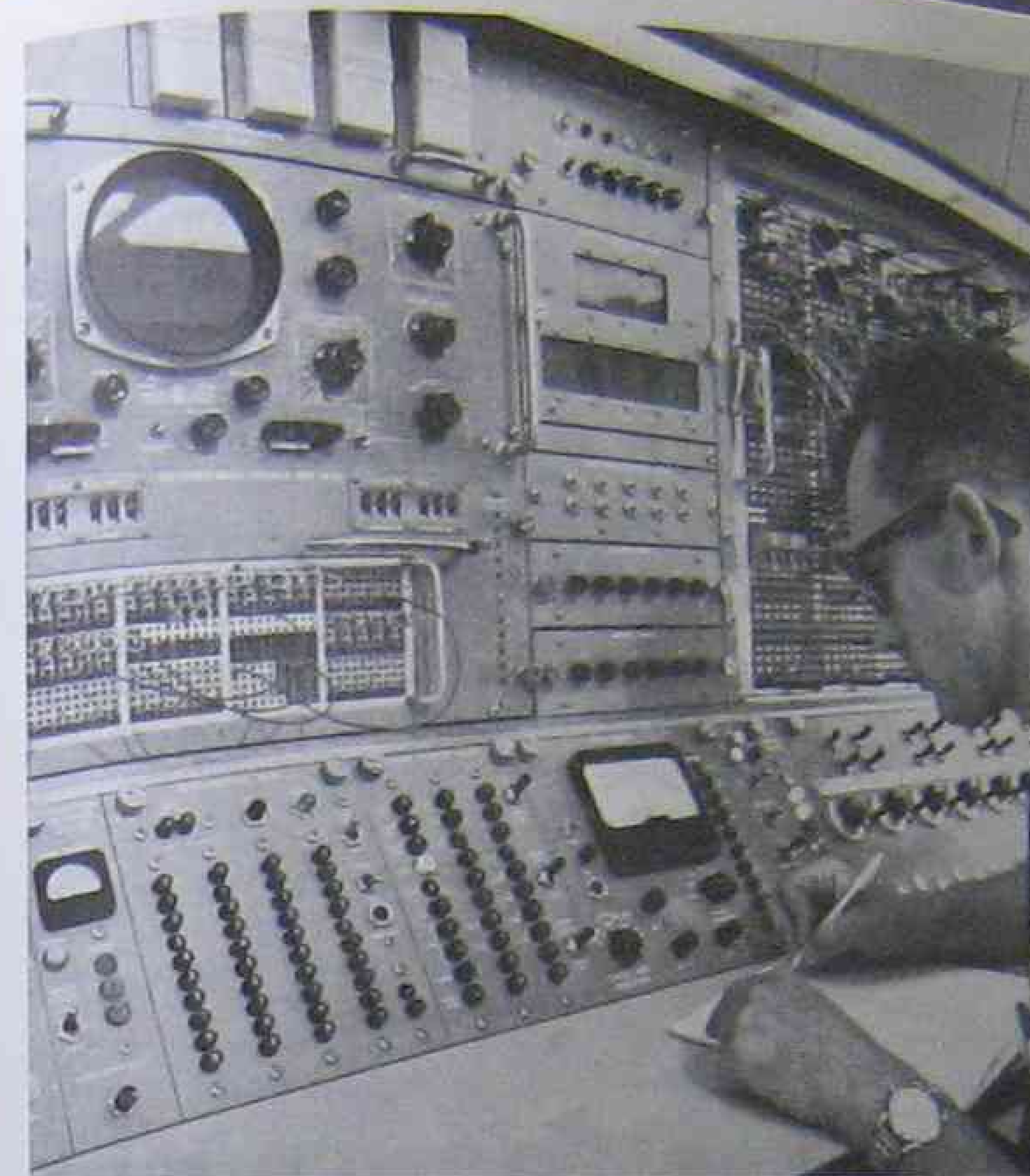
Computer uses have a wide range. Perhaps the primary use is engineering and scientific calculation, for which computers were first designed. Computers can do a wide variety of mathematical manipulation as shown in Fig. 1 in the listing above the arithmetic unit. The particular utility in this application is the high speed with which data can be processed through complex equations. Parameters in an equation can be readily changed to study the effects on results. The scientific computer is generally classified as the general-purpose computer, because it can be adapted (though not always economically) to any type of data-handling problem.

The largest application for digital computers is in the electronic data processing (EDP) field. Here the computer is used for compiling payrolls, customer billing, sales posting, inventory control and general high-volume bookkeeping activities. The high investment or rental cost of the computer is usually more than offset by the reduction in costs of clerical labor and volume of files.

Electric utility systems for several years have been showing high interest in using computers. General-purpose computers are used for payroll preparation, customer billing, inventory accounting, financial control, engineering problem solving. Among the latter are system design and planning studies, forecasting future cost trends and fuel needs for individual generating units.

On-the-line computers do automatic data logging, scanning and alarming of equipment operation, performance calculations, limited automatic machine control, and automatic system-load dispatching accounting for cooling-water temperature and other factors. The ultimate aim is to have computers control generating plant operation completely from startup to shutdown. Limited runs have been made on a few units, but more work needs to be done before the automatic generating plant comes of age.

Success of on-the-line computers depends on the reliability and accuracy of the basic measuring instruments and transducers. Failure here is as fatal as man-failure in making the wrong move. Many of the pioneer efforts have found that computer



5 Complex industrial processes are simulated on analog computer at Minneapolis-Honeywell Special Systems Division, Pottstown, Pa., to develop automatic control systems

programs needed were much more extensive and costly than anticipated.

One approach to plant automation depends on building a mathematical model of the dynamic behavior of the individual components of the plant. The computer program may then be based on this model initially. Field testing of the computer in the plant then shows program modifications needed to conform to actual behavior. This is not as simple as it may sound because an error corrected in one variable must be accompanied by corrections in other dependent variables to keep all factors in the proper overall balance.

Operating experience with automatic on-line computer control has been limited to a few plants. Little Gypsy No. 1 of the Louisiana Power & Light Company was the first to run. The 233-mw unit uses a Daystrom Model 46 computer with a 21-bit word and an 8000-word core memory supplemented by a 100,000-word drum memory. The computer was used for logging prior to unit startup in 1960. Only six tests of automatic control were made, at last report, with only two lasting more than two days. Tests are expected to be completed before the end of this year. Low computer speed limits the response of the system for automatic control.

A computer to be installed with 400-mw Unit 2 at this plant in 1965 will have a speed 15 to 20 times faster than that for Unit 1. The new computer will have a 15-bit word, 28,000-word core memory and 131,000-word drum memory. The system will include 350 thermocouple inputs, 188 analog inputs, 600 contact closure inputs, 6 pulse inputs, 12 analog outputs and 321 contact closure outputs.

Huntington Beach Unit 3 of Southern California Edison Company was another of the first units designed for on-line computer control to aid the operator; the computer has direct control over some plant equipment but it mainly monitors and supervises conventional sub-loops.

The computer scans, alarms, computes and logs performance data; it prints on-demand data; it controls startup, normal operation, normal shutdown and emergency shutdown; it also performs corrective actions.

Computer startup routine includes starting the feedwater system, lighting burners and warming up the boiler, accelerating, synchronizing and loading the turbine-generator to one-third load. For higher loads the operator transfers unit control to the system-wide automatic dispatch sub-loop control.

The original 16,000-word memory of the computer was expanded to a 52,000-word drum ultimately of which 40,000 words are used. A major problem proved to be lack of detail data on sensors, recorders, supervisory instruments and control devices. Grounding of some instruments required modifying the computer input section.

Other problems that plagued the computer and plant shakedown included: 60-cycle noise on thermocouples; poor common-mode noise rejection; sneak circuits in output relay matrix; read-write head malfunctions; noise and timing malfunction in processor circuitry; sensitivity to interruption in feedwater flow through once-through boiler requiring revision of programing; poor reliability of limit switches, relays and other components of the computer.

The numerous program changes led to lack of adequate program documentation. To straighten out this difficulty, the computer was reprogramed and a documentation system set up. Trials showed that using the power plant as the test medium for control suitability was inefficient. So complete simulation tests were run on all computer programs to prove out the logic and sequence.

Experience at Huntington Beach leads to several conclusions for successful computer application: (1) Simulation testing in the computer factory is imperative. (2) Program debugging and documentation should be complete before shipping. (3) On-line process control programs must be flexible and easily changed. (4) Dynamic testing and installation time must be minimized. (5) Extensive customer training must be given before the computer is shipped.

Scanning is a typical duty performed by on-line computers in generating plants and energy-processing systems. Generating plants may have

Survey of digital computers installed in steam-electric central stations

2—Digital computers installed annually

Year	Data only	Control plus data	No. of units over 50 mw	% units with digital computers
1958	2	0	—	—
1959	0	0	—	—
1960	3	1	47	8.3
1961	7	5	44	27.3
1962	8	3	38	29.0
1963	15	11	41	63.5
1964	3	2	46	10.9
1965	0	6	39	15.4
Totals	38	28	255	25.1*

Note—After survey in Jan 1963 an added 8 computers were ordered for probable 1964-65 installation
*—Averaged on 1960-1965

3—Expected benefits

Benefit	Number of installations
Fuel savings	30
Manpower utilization	15
Increased safety	32
Better records	28
Service experience	6
Space economy	3

4—Data processing applications

Data process	No. of computers	No. of units
Periodic logging	40	62
Demand logging	40	62
Startup logging	19	30
Alarm logging	40	62
Sequential alarm logging	11	23
Performance calculations	40	58
Special records	32	46

5—Control applications

Description	No. of computers	No. of units
Startup sequence monitoring	13	18
Startup sequence control	13	20
On-line control:		
Auxiliary equipment	12	13
Burners	5	6
Shutdown sequence monitoring	10	16
Shutdown sequence control:		
Normal	11	14
Emergency	10	12
Direct digital control	13	20

6—Analog inputs per generating unit

Scan rates, points/sec	Units	Thermocouples	Units
1- 4	1	0- 99	23
5- 9	20	100-199	9
10-14	5	200-299	10
15-20	4	300-399	10
Over 20	9	400-499	2
		Over 500	2

Mv or ma	Units	Resis elements	Units
0- 24	12	0	2
25- 49	14	1- 9	11
50- 69	6	10-29	12
70- 99	5	30-49	23
100-149	5	50-69	1
150-199	4	70-99	4
Over 200	1	Over 100	1

Transduced pneumatic	Units	Slide wires	Units
0	24	0	22
1- 9	9	1- 4	9
10-29	7	5- 9	5
30-49	7	10-19	0
		20-39	2

7—Digital inputs per generating unit

Total inputs	Units	Alarm contacts	Units
0- 49	28	0	16
50- 99	9	1- 24	6
100-299	7	25- 49	7
300-499	4	50- 74	1
Over 500	8	75- 99	8
		100-499	6
		Over 500	8

Pulse accum	Units	Control inputs	Units
0	8	0	32
1- 9	28	1- 99	8
10-19	16	100-199	3
20-29	2	Over 200	7

Scan rate, pts/sec	Units	Scan rate, pts/sec	Units
0	7	100-499	6
1-24	3	500-999	5
25-49	1	Over 1000	6
50-99	3		

300 to 600 analog points to measure important cycle conditions, about 100 to 300 may be in the boiler and furnace. These measurements are made by temperature, pressure, flow and level transducers that pose problems in signal cabling, shielding practice, signal noise and filtering and calibration.

As many as 600 contact closures may be monitored in a plant using automatic sequence control. For simple scanning and logging computers there may be as little as 50. Problems to be coped with include contact reliability, bounce and noise.

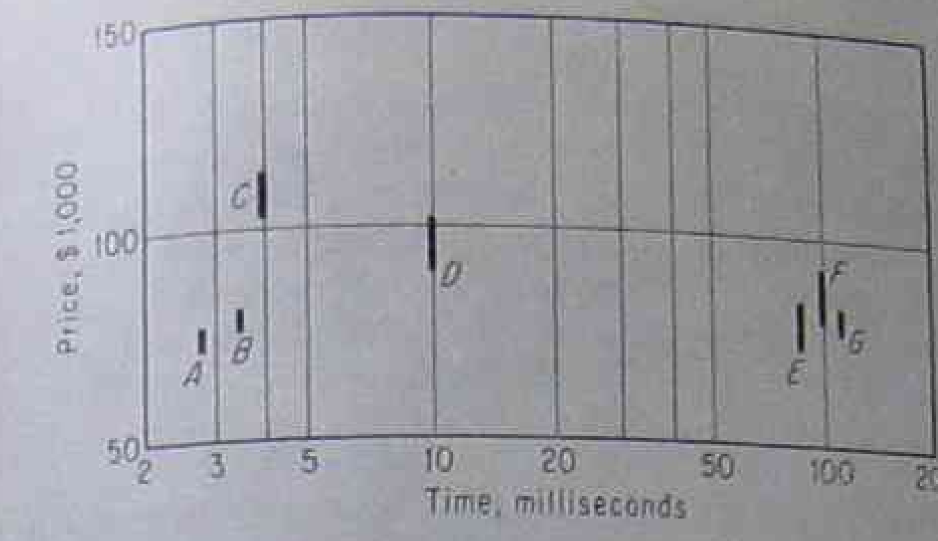
Alarm and logging functions for an on-line computer may vary from 200 for a small system to 400 on a completely automated system. Studied effort must be made to avoid logging too much data. All points scanned need not be logged, even for historical information. Only the data needed by an operator to make decisions should be logged. Performance indices and operating guides can be calculated and displayed. These indices may be alarmed when they are useful guides.

Simpler forms of computers for plant control stop at the alarm that signals the operator of off-normal conditions. The next step would use the alarm pulse to start corrective action in the energy system being monitored. This step involves a sharp rise in computer cost because of the great expansion in hardware needed to implement such a system.

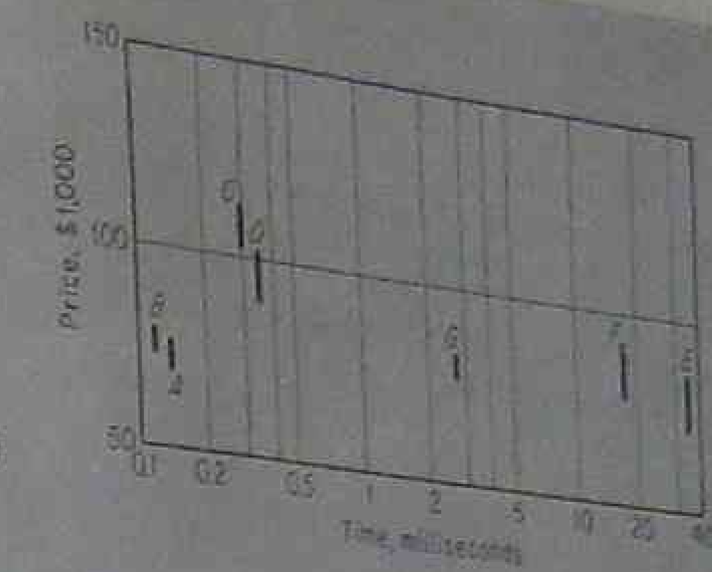
Pre-engineered or standardized computer systems and programs are practical because of less system engineering, greater reliability, reduced lead time and installation time. But this saving in investment is realized at the cost of less flexibility in choosing number of points, type of sensors and functions to be fulfilled.

Sequence monitoring by computers becomes critically important during plant startup and shutdown operations. Here again the computer may just alarm when an improper step is taken by the operator, or take action itself to correct the deviation under a fully automatic system.

For either arrangement the computer must be completely programed to assure safe operating procedures. Three phases make up sequence monitoring: (1) identifying the next step or noting an operation omitted by



6 Execution time for an arithmetic benchmark problem shows wide variation of ability in different makes of digital computers



7 Execution time for logical benchmark problem shows no clear relation to price as for the arithmetic problem in Fig. 6, left

printouts (2) checking turbine acceleration and generator loading to guide the operator in correcting deviations from program (3) monitoring manual operations and alarming any misoperation.

Computer programing to perform startup and shutdown sequence monitoring may need about 4000 instructions. But for automatic sequence control, as many as 20,000 instructions are needed. Details of operating procedures, unit characteristics and plant instrumentation must be thoroughly known. Each plant is unique, and little work done on other plants can be applied. Only the overall principles of programing appear useful as general guides.

Performance calculations useful to a plant operator include: boiler efficiency, turbine efficiency, feedwater heater performance, condenser performance, overall cycle heat rate. Whenever any of these performance indices deviate, the operator may investigate the cause. The analog or digital computer may be programed to perform these calculations at stated intervals or on demand.

To achieve acceptable accuracy in performance calculations, instrument accuracy, location and calibration must be of a high order. Any deviation in accuracy correspondingly degrades the accuracy of the answer and may raise concern about main equipment performance unnecessarily. Flow stratification in pipelines and ducts can have important effects on pressure and temperature transducers. So these must be placed to minimize any deviations from average values over the entire load range. Sensors should be calibrated after installation in the plant cycle, to include the effect of the entire measuring circuit. Performance measurements should generally be made with the energy cycle in a steady state. Transients during load changes do not stay in phase and so would give misleading performance results.

Evaluating control computers is critically outlined by G C Hendrie and R W Sonnenfeldt, The Foxboro Company, in their paper presented before the 6th National Power Instrumentation Symposium of the ISA at Philadelphia, Pa., on May 15, 1963. Computer performance should be rated according to: (1) reliability or consistency of performance (2) speed margin—how the computer copes with the worst-case time combination of events (3) memory storage margin—provisions for worst-case data storage, retrieval and working space.

Computer speed depends on the overall actions needed to perform a calculation. These may take anywhere from 10 to 100 times longer than the time needed to simply add two numbers, often quoted by manufacturers. In addition a drum or disk memory with 150 microsecond add time may have memory access time of 16,000 microseconds; this obviously is the controlling factor on computer speed.

Word length also affects computer speed. One with 24-bit words and another with 12-bit words seem to have identical operation rates and memory access times. But there will be as much as a 2:1 variation in the speed at which they do a group of arithmetic operations to the same degree of precision. Overall, problem-solving speed should be compared to estimate the relative usefulness of computers.

The number and power of the operations in the machine's instruction complement may not all be useful in a given application. These features should be critically balanced against the control needs in an energy processing system or generating plant.

Bench-mark problems should be used to compare computers for relative suitability to solving specific control problems. Each computer should be programed for a given application to reach a conclusive choice. Unfortunately this attack is very expensive, so a good compromise test uses shorter typical trial problems with representative arithmetic and logical manipulations to tryout the computer.

One bench mark problem to test arithmetic problem-solving capability consists of a pair of simultaneous equations in two unknowns. This problem took account of word length. Fig. 6 relates the speed for several machines against their cost.

In some control applications the logical-problem-solving ability may be more important than the arithmetic aspect. In the logic function the computer uses information transfers, manipulations and comparisons all of which use time. Fig. 7 relates logic speed for some computers against their cost, for a specific test problem.

Memory size. An on-line control computer cannot deal with a real-time problem unless all instructions defining the action are stored and available when needed. Distribution of storage between high-speed random-access memory sections and lower-cost lower-speed cyclic access sections, such as drums and disks, influence computer speed. Good practice stores an image of the high-speed working memory in one of the slower speed backup memories.

In machines with 12- to 15-bit words more than one memory word may be needed to store an instruction or data item. Comparing bench mark problems will show the relative need of memory addresses between different computers. Experience has shown urgent need for machines with expandable memories. The tendency has been to completely underestimate the capacity needed on first approach to an application.

Reliability of computers should be evaluated on actual field experience, but little of this information is available. Another few years of shakedown of these new devices should yield representative data. Critical appraisal of design conservatism can help in judging computer reliability. The mean time between failure (MTBF) should be in the thousand-hour-plus category. Ambient temperature specifications should permit operation in the 50-to-120-F range.

The computer should be protected against incidental power failure. Special attention must be given to protecting data stored in the memory.

The shape of control computers is given in a survey made by the Power Industry Division of the ISA reported by R A Russell of Black & Veatch at the 6th National Power Instrumentation Symposium in Philadelphia, Pa., May 13, 1963. Tables 2 to 7 list some results of the survey which covered only digital on-line computers in central steam stations on utility systems. The results cover about 90% of the installations.

These include 42 computers serving 66 generating units. See also POWER, October 1962, p 148 for a survey of central-station data loggers and computers. Tables 2 to 7 show that computers are limited to larger generating units. About 75% of the utilities feel that anticipated fuel savings, increased safety and better records justified installation of the computers. Almost all computers have periodic, demand and alarm logging as well as performance calculations incorporated. About 11 of the computers provide full startup and shutdown control.

What's in the future? Past rapid development of computers may seem to make a look into the future cloudy at best. But demands of modern and future technology assure that development momentum will carry on into the next decade.

Purely mechanical computers have been with us for many years, usually needing a human brain to direct each action. First attempts at automating the computing process to speed it up, and handle more complex and greater quantities of data, used electromechanical relays. Individual actions of components of the computer needed milliseconds to complete.

Introduction of the vacuum tube shrank the physical size of computers and speeded up their operation to the order of microseconds, 10^{-6} or millionths of a second. Minimum memory cycle times were about 10 microseconds, transfer times one microsecond and switching about 1/3 microsecond.

Today's computers use semiconductor junctions instead of vacuum tubes for rectification, amplification, capacitance variation and now tunneling as the latest development. Transistor action (control and amplification) is realized by combining two junctions and in the laboratory speeds of the order of nanoseconds, 10^{-9} or billionths of a second, have been achieved. Intensive investigation now going on with tunnel diodes show they have a time constant of less than 10^{-13} second or 0.1 picosecond (10^{-12}).

Thin films of ferromagnetic materials, iron, nickel, cobalt and their alloys, promise a significant speed up in computer actions. Using these for memory and register, their state can be changed in nanoseconds.

Cryogenic techniques using the association between magnetic fields and superconductivity at temperatures near absolute zero may be used in future computers. Magnetic time constants are on the order of 10 picoseconds and thermal time constants about 1 nanosecond.

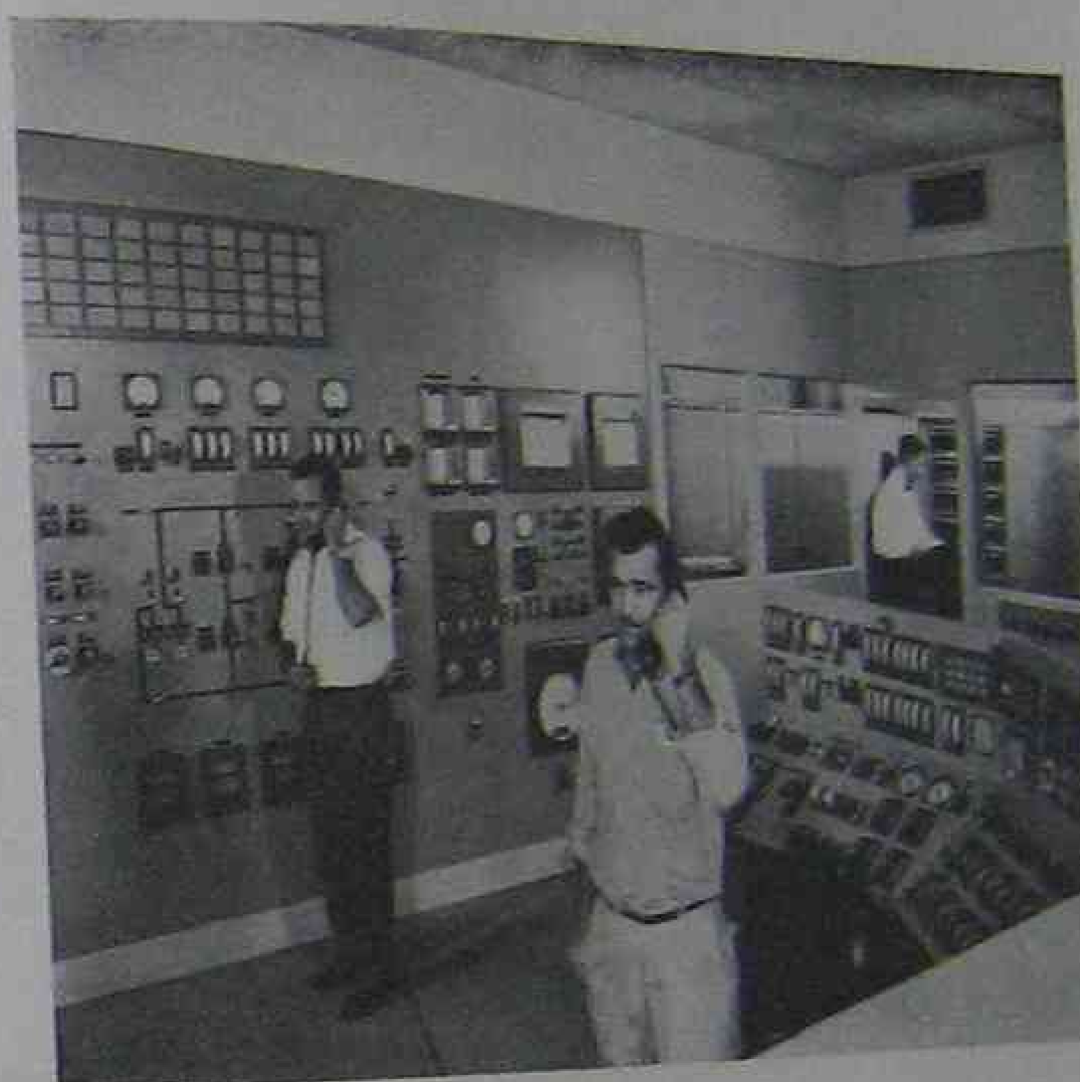
With high-speed phenomena we run into an interesting restriction—the speed of light. The well-known 186,000 miles per second is equal to 11.8 inch per nanosecond. In computers the speed of information along the electrical circuits will be about 1/2 to 2/3 of this speed. This means that circuit lengths will be a vital factor in limiting computer operational speed. The high frequencies involved in these compact circuits raise the need for special design techniques and the need for using distributed constants instead of the more familiar lumped constants.

Programing still uses the most time of any phase of total computer operation for problem solving. So even if computer time were cut to zero the saving would not be significant in overall time needed. On the other hand saving in computer time is important in control applications because processes can be held more closely to optimum levels. In fact, in some missile-guiding applications, computers prove to be too slow for successful solutions; the nanosecond speeds may be the answer.

For problem solving applications, efforts are being made to reduce preparation time by automated programing techniques and better computer organization.

Nanosecond techniques will probably be used in serial computers, in which a series of pulses over one circuit will transfer all the information between components. Our present "megacycle" computers are largely parallel machines using parallel circuits to handle simultaneously all the bits in a word. The serial computer would be a more compact machine with significantly less hardware. It's expected this design would be more reliable, have lower power consumption and adapt more easily to controls.

CONTROL ROOM of modern thermal power plant houses computer, print-out units



COMPUTER CONTROL:

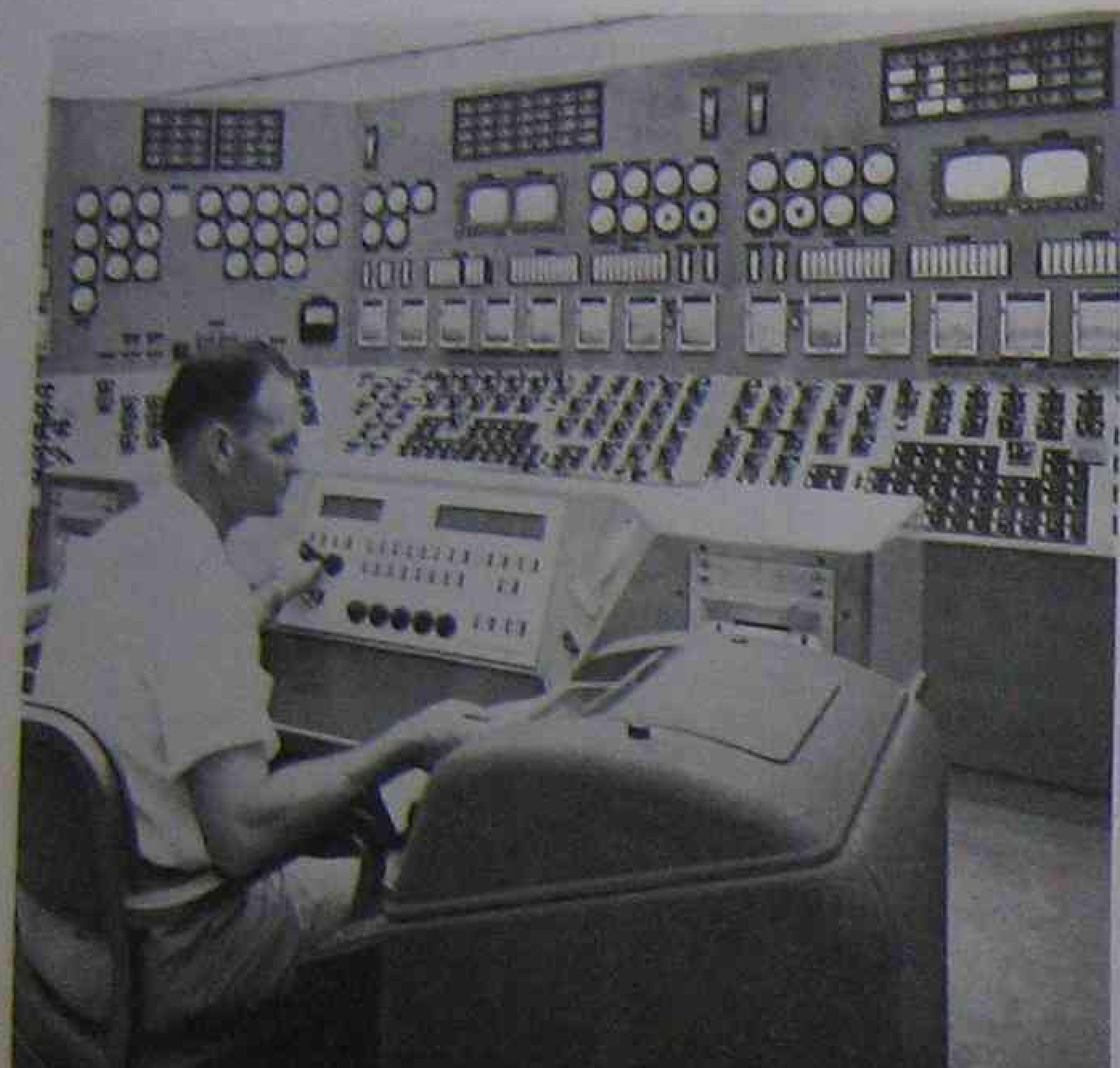
Power plants join industry-wide advance

With more than 400 industrial process computers ordered or in use, central-station engineers are leading the way to a new appreciation of automatic control technology

By R K EVANS, Assistant Editor

Evolution of electronic computers can be divided into five-year periods, each characterized by some significant development or trend. From 1945 to 1950 there was a period of fundamental electronic design which gave birth to today's computer "hardware." From 1950 to 1955 attention was focused on the solution of scientific and engineering problems, and the next five years saw a great upswing in commercial data-processing applications. Today there is comparable activity in the field of real-time, on-line computer control of paper and steel mills, power plants and refineries.

What problems have been encountered in today's computer applications? What developments will take place in the next few years? On the following pages, as we study two typical "case histories," we will discuss the lessons learned and the trends established in modern process plant control.



GEORGIA POWER COMPANY'S McDonough plant uses digital computer to monitor two 250-mw units. Operator inserts fuel analysis data to obtain continuous record of heat rate

First requirement . . . . . . increase the accuracy of plant instrumentation

When Georgia Power Company planned two 250-mw coal-fired units at its new McDonough plant, a decision was made at the design stage to incorporate digital computer monitoring. Behind this decision lay three compelling reasons: (1) Existing boiler control problems increase with size of unit; continual adjustment of reset, rate and proportional band settings of conventional subloop control systems may be necessary to obtain stable control conditions. (2) Cracking of turbine metals, failure of boiler tubes and maintenance problems can often be attributed to wide and frequent variations in steam pressures and temperatures, both of which can be held within narrower limits under computer vigilance. (3) To obtain maximum usefulness from the Southern Company's Early Bird computer, controlling dispatch and transmission over the four interconnecting systems of which Georgia Power is one, more accurate loading information had been found necessary from each of the system's thermal and hydro generating plants.

The resulting analysis of boiler-turbine system dynamics has served as a model for many subsequent computer-monitoring installations. At the time that work on McDonough started, little was known of boiler dynamics. Both analog and digital computer simulation was developed to establish primary and second-order effects and determine what data is relevant in deriving basic constants. For instance, drum pressure is not solely a function of fuel rate, but also of feedwater flow, burner position, gas recirculation, superheat spray water flow, waterwall slagging and other factors. Extensive study was therefore made of the cross-effects between these variables and of the best way to incorporate them into an overall control system.

Most far-reaching of the findings was the need for much greater accuracy in critical sensors and transducers when their signals form the input to an on-line digital computer. The four major types of measurement—pressure, temperature, flow and power output—were found to require a maximum error of $\pm 0.25\%$ of the measured variable if input error to the computer was to be held within acceptable limits.

Primary flow measurement selected was that of condensate to the deaerating heater. A flow section with removable throat-tap flow nozzle calibrated over a Reynolds Number range from 2×10^6 to 6.5×10^6, enables differential pressure across the flow nozzle to be measured by a manometer with a servo-system following the mercury level. Latter is indicated by digitizer attached to a rotating shaft in the servo system; computer senses this as various combinations of contact closures.

Pressure measurement is through accurate pressure transducers with a long-term accuracy of $\pm 0.15\%$. Input to the computer is digital in binary-coded decimal form; pressure is read in 300 milliseconds with a resolution of one part in 2500.

Temperature readings are the only critical measurements requiring analog-to-digital conversion. Chromel-constantan thermocouples are duplicated where temperatures have greatest influence on results. Reference junctions and thermocouple elements are made of selected and matched wire, and are controlled to within 0.1 deg of set point.

Power measurement is through a three-element watt-hour meter system using calibrated current and potential transformers. Three-phase calibration minimizes the effect of mutual induction between coils when currents and potentials have phase relationships 120 deg apart, insuring the desired accuracy.

On-line computer selected for monitoring the McDonough units is a General Electric GE-412 digital stored-program unit, with a 256-input, 20-point memory event recorder directly coupled to the computer to monitor sequence of events during abnormal operation. Under normal conditions memory is available for alarm storage.

In operation, fuel analysis and similar data are inserted via the operator's console. Results of performance calculations (boiler efficiency, heat rate, and divergence from reference cycle) together with continuous pressure, temperature and flow readings are typed out on the console typewriter. Information, such as boiler and turbine efficiencies, is also available for visual display and trend recording, affording a continuous check on operation.

Analysis of plant operation precedes choice of computer

Today's engineers are finding greater justification for installing computer systems. Multiprogramming, long under development, is now established and available in many computers. Thus, an on-line system can handle data-processing or perform calculations during pauses between its real-time control activities.

More important, users are gaining in knowledge and sophistication in their choice of equipment. No longer entirely dependent on the computer hardware manufacturer for system design, a user finds it easier to apply computer control techniques to the requirements of his particular plant, whether it is a steel mill or bakery, sugar refinery or boiler-turbine unit.

First step following the decision to streamline plant operations by installing computer control is a searching analysis of the process itself. Many of the early failures of loudly-heralded computer-controlled plants were due to neglect of this fundamental requirement. One approach is to build a mathematical "model" of the individual plant components and their dynamic behavior. This can serve as a basis for the proposed computer program.

But success of an on-line computer depends very largely too on the accuracy and reliability of the basic measuring instruments, sensors and transducers. Many pioneer efforts were unsuccessful because of the accumulation of errors as instrument readings were converted to digital form for processing by the computer and later reconverted to analog input to pneumatic or electric actuators. Account of McDonough plant above emphasizes the importance of recognizing sensor and instrument limitations *before* considering a computer program.

From data obtained during this preliminary plant analysis, the potential user can specify the tasks which a control-computer installation must be able to perform. Such criteria as cost, reliability, ease of programming, and life expectancy must all be taken into account. So must "maintainability"—too often, in the past, diagnosis and location of a fault have lengthened computer down time to an unnecessary and uneconomic degree.

Expensive result of neglecting these criteria was experienced by Southern California Edison at its Huntington Beach power plant, which, like Louisiana Power & Light Co's Little Gypsy, was one of the first units designed for on-line computer control. Plagued by such fundamental problems as inaccurate sensors and recording instruments, poor reliability of computer components, and need for frequent program changes, Southern California Edison's experience there has led to a major revamping of computer-system requirements.

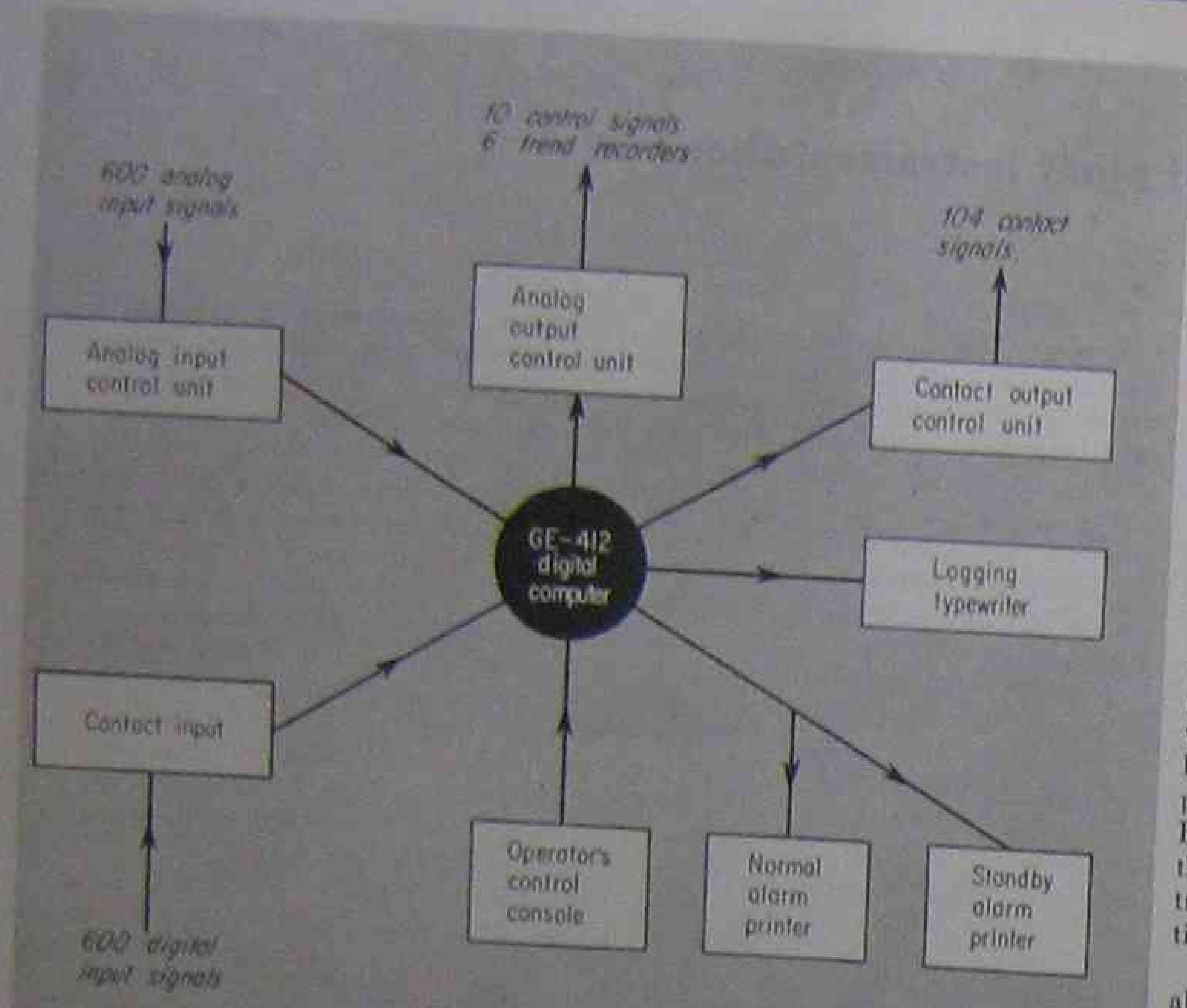
Success of subsequent installations at Alamitos and Etiwanda can be attributed largely to lessons learned at Huntington Beach. The five most important are:

(1) Complete analysis of system must be carried out before specifying computer requirements.
(2) Accuracy of critical measuring and actuating devices (pressure, temperature and flow) should be no less than $\pm 0.25\%$ of the measured variable.
(3) Simulation testing must be carried out in the manufacturer's works; program debugging and documentation should also be complete before installation.
(4) Control programs must be flexible and easily changed.
(5) Extensive personnel education and training pays dividends far greater than its cost.

Two contrasting approaches to this latter need are illustrated by recent installations of Westinghouse PRODAC 510 computers; Georgia Power Co, whose operators are already familiar with previous installations, felt that no major training program was necessary. Pacific Gas and Electric, on the other hand, with no comparable experience to draw on, insured that all operators at its Contra Costa plant took part in a full training program—amply justified when units 7 and 8 made their initial roll under computer control.

Importance of adequate customer education cannot be overemphasized. If they have not been fully trained in its use, operating personnel can make or break any computer system, particularly at a time of emergency or plant malfunction. The aim of all computer manufacturers is complete automatic control without human intervention. Nevertheless, the guiding rule, "When in doubt, let the operator run the plant," still applies, especially in such hazardous conditions as power plant operation or steel-making. The computer, therefore, in addition to its monitoring functions, must provide the operator with information on plant status and trends. Only in this way can he be continuously aware of minute-by-minute plant conditions, readily able to override or assist the computer.

Winning operator's confidence has often proved an unexpected problem. Experienced plant operating personnel, trained to master the vagaries of a complex process plant, are often unable to understand how a newly-installed computer functions. Input signals from faulty plant equipment can cause a shutdown which, in the operator's eyes, is computer malfunction. Many abnormal data input signals are given unrealistic limits in the program. Consequently, the computer gives erroneous alarms and may even shut down the plant. Experience has shown that careful review of such variables enables non-valid alarms to be eliminated or the limits widened, increasing operators' confidence in the computer system.



BLOCK DIAGRAM of computer control system installed at McDonough plant. Computer receives 1200 input signals from sensors and transducers, sends out 120 control signals

Etiwanda unit 4... ...12 months of successful computer control

Ultimate aim in application of process-control computers is to have the computer solely responsible for all plant operations from startup to shutdown. Despite complexity of modern thermal power plants, central-station computers approach this ideal more closely than in comparable industrial applications.

On previous page we outlined the factors to be considered before a computer installation can be specified. But while Georgia Power limits its McDonough computer system largely to plant monitoring, Southern California Edison's 310-mw Unit 4 at Etiwanda is the first to be under full computer control from light-off to line synchronization at operating load.

Based on previous installations (not all successful) at its Huntington Beach and Alamitos plants, Southern California Edison has concentrated much experience into the new Etiwanda control system. Using a GE-412 digital computer basically identical to that installed at McDonough, the automatic control system

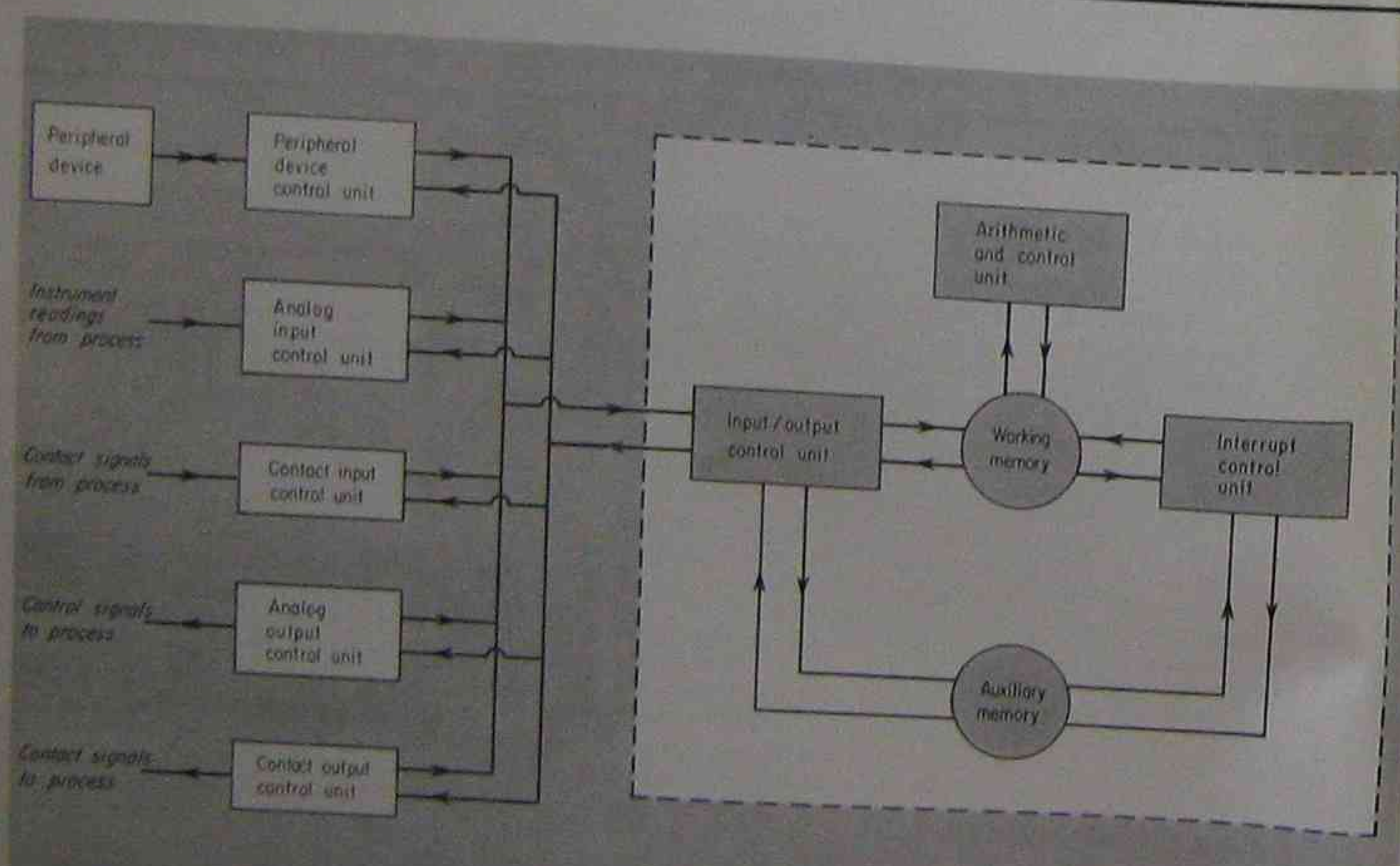
- confirms that prestart conditions (temperatures, water levels, valve settings, furnace condition and water treatment) are in accordance with programmed settings
- performs turbine trip tests
- establishes water circulation and air flow through the furnace
- lights and monitors burners
- phases turbine h-p and l-p shafts
- accelerates turbine up to 3600 rpm, synchronizes unit to system frequency, and loads generator to 65 mw.

During operation the computer continuously scans 1084 functions for possible alarm conditions, logs 56 values every half-hour or on demand, and makes 22 performance calculations which vary in complexity from simple totalization to determining net heat rate. Operator is thus relieved of most routine responsibilities and has more time to optimize plant performance. Should he require a continuous trend recording of any of the major plant functions, he can monitor it by putting the particular input on one of six trend recorders in the control room.

Should the computer fail, the operator can run the plant with conventional subloop controls; all computer outputs are automatically returned to "normal." Two most complex dynamic control functions handled by the computer are boiler warmup and turbine speed control. Experience with the latter at Huntington Beach, where it was controlled as a separate subloop, suggested that the Etiwanda speed control be handled as a closed loop directly through the computer, with contact outputs operating the turbine stop-valve and bypass valve motors to raise or lower turbine speed.

Boiler warmup is computer-controlled from light-off to full rated pressure. One analog output regulates fuel-valve opening while another adjusts the steam pressure set point after turbine synchronization. Six fuel-change routines are also programmed into the computer to initiate and monitor transfer from gas to oil firing and vice-versa. A further diagnostic and control routine handles emergency transfer to oil firing if gas supply should fail.

Emergency shutdown routines include reinitiation of the scanning program after a trip to remove scan points that could cause false alarms. Considerable extra capacity is available for future refinements dictated by experience. Normal and backup power supplies to the computer are provided by its own ac motor and battery-powered dc motor/ac generator set. At present Etiwanda 4, with only routine maintenance, has been under successful computer control for some twelve months.



LOGIC CAPABILITY of process-control computers requires some combination of all the units shown above. Computer itself consists of equipment within dotted line; peripheral devices include tape and card readers and logging typewriters, all aiding the operator

Modular concept insures computer-system flexibility

Typical process-control system includes a wide variety of electronic equipment, as shown in the block diagram at left. Generally considered as part of the computer are arithmetic/control unit, working and auxiliary memories.

Arithmetic and control portion of the digital computer provides the logic and calculation capacity needed to evaluate and control output signals to the process plant. Working with instructions from the memory unit and data from sensors and transducers measuring plant conditions, the arithmetic unit performs calculations according to programmed instructions and transmits the results to the input/output control unit.

Memory unit contains instructions, usually as magnetic signals on core or drum, which cause computer to perform the required functions. Storage is also provided for data required to solve calculations, normally programmed into the memory, and for data transmitted from instrumentation within the plant.

Interrupt control unit provides the necessary signals to the arithmetic and control unit when plant situation warrants interruption of the program for priority action. This unit stops normal sequence of instructions within the arithmetic unit and, after noting the point of interruption, triggers entry to the higher priority routine. Normal sequence is resumed automatically.

Many peripheral devices may be linked with the computer. These include magnetic tape, paper tape and card readers, teletype printer, line printer and typewriter. Use is self-explanatory; each has access to a control unit containing the circuitry necessary to transmit information to or from the working memory.

Contact-input control unit provides circuitry to transmit the status of contacts located throughout the plant (limit switches, pressure switches, etc) into the computer memory. This input is in digital form, suitable for immediate use in the computer.

Analog/digital converter selects input signals in analog form (voltages representing pressures and temperatures, for example), amplifies and converts the signals to digital form, then transmits them to the computer memory in the same way as contact-input unit.

Output-control units are similarly either analog or digital (contact). The latter transmits signals to control on/off equipment and certain peripheral devices. Analog control sends out variable-voltage signals to set electrical controllers throughout the plant or to position valves, thus providing closed-loop capability of the computer-control system. Analog outputs are also used for trend recording and other noncontrol functions.

Direct digital control (DDC) is at present much in the news as a likely replacement for analog control. Major advantage is that DDC would abolish need for digital/analog converters and give computer more direct control over plant equipment, as well as remove one more source of spurious signals. However, until we have plant equipment which will respond to DDC signals, analog control will continue to be the principal medium for transmitting computer commands to inplant actuators.