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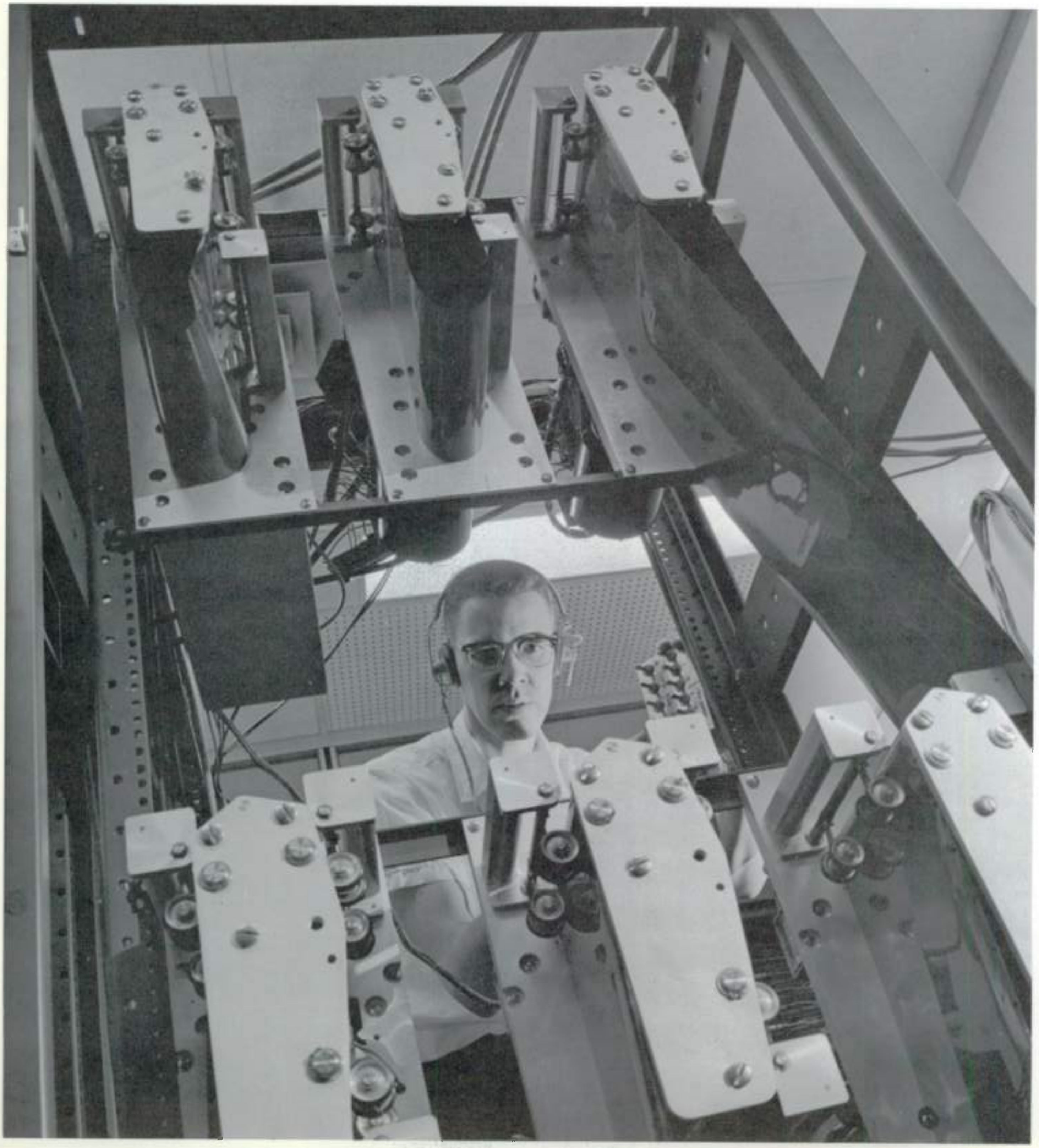
September 1965



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Left: A computerized teaching system being assembled at Stanford University has audio equipment to enable the computer to talk to the students. It will be used at Stanford's Institute for Mathematical Studies in the Social Sciences, one of the nation's major learning-research centers. The battery of 12 random-access audio units (six of which are seen in the photograph) is controlled by a Prodac 50 computer. Ability to deliver computer-controlled verbal messages to the student is a capability not previously available in teaching machines.

The audio units are essentially highly developed tape machines. Their tapes contain such information as lesson instructions, questions, and correct answers, which are communicated to the student by the computer according to the directions programmed into the machine. Students have access to any information on any tape in the machine, and the tapes are readily changed. The audio system was developed by the Westinghouse Research Laboratories.

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Prodac

Cover Design: Magnetic tape recording of power usage data on electric utility systems is the subject of this month's cover by artist Thomas Ruddy. The design symbolizes the reflecting patterns used on the meter disc. As the disc rotates, reflected light from unpainted surface areas on the disc causes a photoelectric sensor to initiate pulses that are recorded on magnetic tape.

Magnetic Tape Recording on Electric Utility Systems

by C. J. Snyder
D. D. Weers

A new magnetic tape recording system can automate the gathering and processing of data for system load studies and demand billing.

The desirability of automatic metering and processing of power usage data for such applications as system load studies, rate analyses, and demand billing has been recognized by utility companies for several years. Until recently, however, the complexity of both the process and the required equipment has delayed the installation of automatic metering systems. Now, a magnetic tape recording system developed by Westinghouse meter engineers makes automatic metering and processing feasible for even the most complex system interconnections or rate structures. With power usage data recorded on magnetic tape, manual reading and interpretation of charts or printed tapes can be eliminated. And the wealth of data available from a magnetic tape system will permit rates to be more closely aligned with actual cost of service, even on the most complex contracts.

With the present trend to the use of computers for everything from system studies to bill preparation, a tape recorder system provides the means for automatically entering power usage data into a computer. A translator automatically converts raw data from field tapes into a form suitable for computer entry. In cases where such tasks as billing are not already done by computer, a magnetic tape recorder system can make the transition to the computer all the more desirable.

Westinghouse magnetic tape recording equipment has now undergone extensive field testing and development on several utility systems, and has demonstrated the reliability and accuracy necessary for automatic demand billing as well as a variety of system load study applications.

Magnetic Tape Recording

A practical means for developing a system suitable for automated demand billing became apparent in 1960 when several utility companies suggested that the Westinghouse DSL load survey recorder, introduced a few years previously, might be extended into the billing field. This original load survey equipment, of which there are currently more than 5,000 units in service, was not intended for revenue billing, and thus was not designed with the required reliability for this type of service. But, using the same basic elements of the original load survey system, a more sophisticated and much more reliable tape recording system has been developed.

The basic components of the new magnetic tape system are shown in Fig. 1. Input to tape recorders comes from meters equipped with pulse-initiating devices, which provide pulses at a rate proportional to the quantity being measured by the meter. Thus, any measuring device that can be made to emit or send pulses proportional to the measured quantity can be used. For example, kilowatts can be readily recorded by sensing with make-and-break contacts the turns of a kilowatt-hour meter disc and sending this information in the form of pulses to the tape recorder.

Pulses from a single meter are recorded on a single tape track; another track on the same tape is used to record the time interval. The number of pulses during a time interval is a measure of demand; total pulses are a measure of usage.

After recording for a selected period, the tape is removed from the recorder, and data on the tape is translated into computer-entry form (computer tape or punched cards). The computer then processes the data and produces the desired printout, such as a load-flow analysis or a bill. Since the computer has all power usage data along with interval identification, this information can be used for a variety of system studies.

Pulse Initiators

Any device that can provide a make-break contact operating at a rate proportional to the quantity being measured can be used as an input to the magnetic tape recorder. A new photoelectric pulse initiator (Type CD-24) has been developed especially for use with rotating-disc meters. By using reflected light from unpainted surface areas on the meter disc, a photoelectric sensor can be made to actuate a contact switch without imposing a load on the meter.

The CD-24 pulse initiator is designed to provide a three-wire pulse output by means of two photocells with a light source mounted between them. The photocells are light-sensitive silicon PNPN switches, which operate as light-triggered controlled rectifiers. The photocells are mounted at different distances from the center of the disc and the reflective areas are likewise on different radii of the disc so that only one photocell is exposed at a time. The pattern of the unpainted areas on the meter disc provides for alternate exposure of the two photocells.

Exposure of the photocells operates a polarized, magnetic-latching relay in the recorder. Since the relay is magnetically latched on each side, it cannot operate unless the photocells are alternately exposed, thus avoiding the danger of false pulses. The completely solid-state circuitry eliminates "hard contacts" between initiator and recorder.

Another pulse-initiator design (CD-21) resembles the CD-24 in construction and circuitry, but the polarized magnetic-latching relay in the recorder is replaced with an external mercury-wetted latching relay and power supply.

WR-2 and WR-4 Tape Recorders

The output from the pulse-initiating device is fed to a WR-2 or WR-4 tape recorder, where it is transformed into an electrical signal suitable for energizing the tape-recorder head. All of the electronic circuitry required by the recorder is placed on a plug-in printed-circuit board so that if field maintenance is required, the board can be simply replaced. The WR-2 recorder has one track for the input from a pulse

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initiator and one track for the timing pulse; the WR-4 recorder operates in the same manner except that three tracks are provided for pulse-initiator inputs.

The time-interval pulses are obtained from a sealed-reed switch, which is actuated by a synchronous clock motor. The beginning time of day and elapsed time of the beginning interval are set on the recorder by the serviceman when he installs a fresh tape. The recorder can be supplied to provide interval pulses either every 15 minutes, 30 minutes, or 60 minutes to accommodate the desired demand interval.

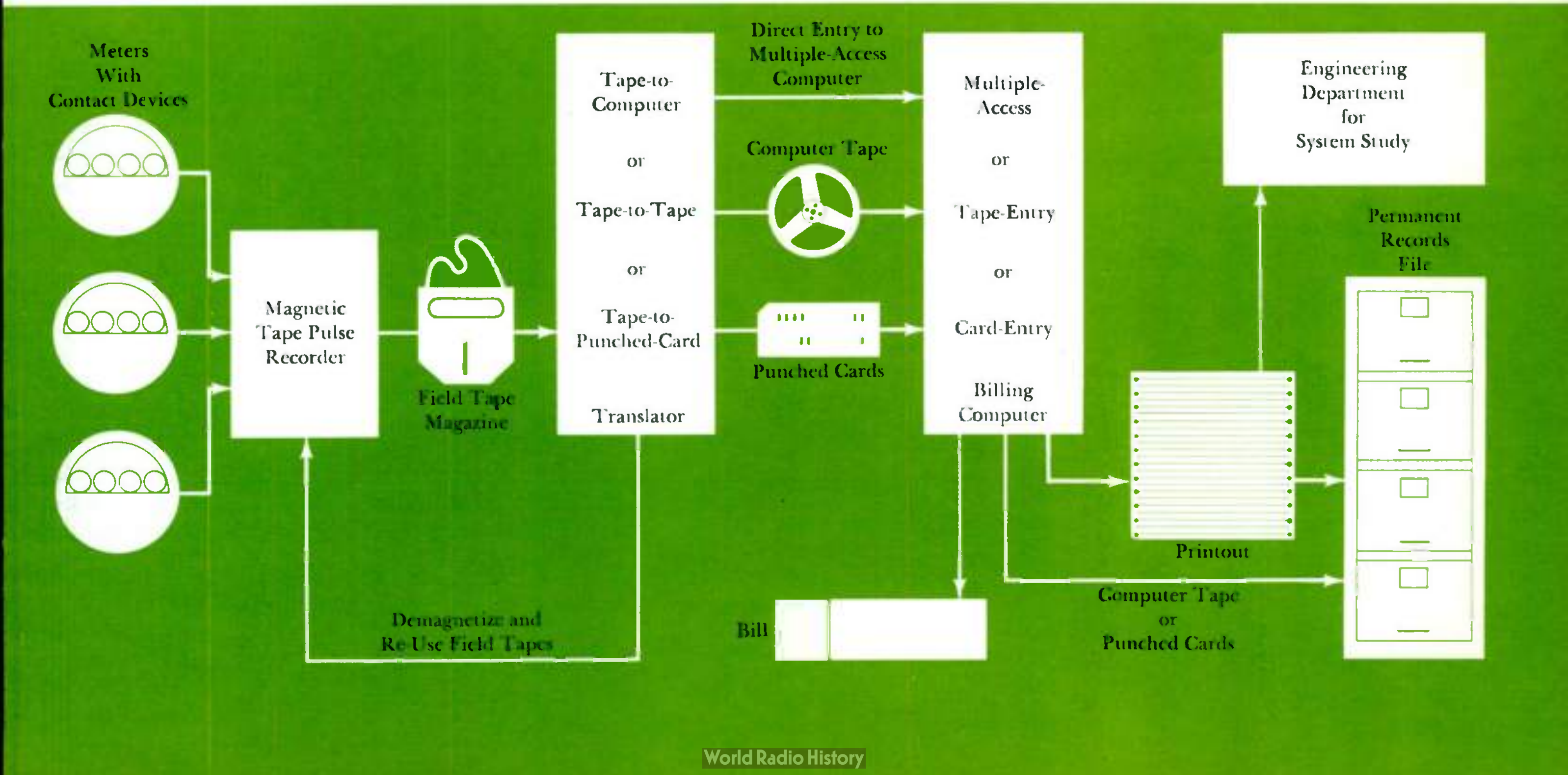
Recorder tapes are wound on plastic reels, which are mounted in cartridges so that the tape reels need not be handled by servicemen. The recording tape is instrumentation type, ¼ inch wide and one mil thick. Speed through the recorder is 8.6 inches per hour so that a 625-foot tape provides a 36-day supply. Since the tape must move approximately 0.002 inch between pulses to avoid interference from one pulse to the next, the recorder can accept a maximum of 4000 pulses in a one-hour interval (1000 per 15-minute interval, or 2000 per 30-minute interval).

Since a magnetic tape does not allow visual inspection of the information recorded on the tape during the month, several additional accessories have been developed for checking the information recorded. For example, a register for demand during the present interval, maximum indicated demand, and total pulse count recorded on the tape is available as well as total pulse counters without demand indication. Test jacks allow an earphone to be inserted in the recording circuit to detect pulses coming into the recorder. The circuit is designed so that any pulse audible through the earphone has also triggered the recording head. Barring failure of the head itself, this is assurance that the pulse is being recorded on the tape. Other options available include a battery carry-over circuit, which can provide interval pulses and continue moving the tape during a power outage for up to a three-hour period on a self-contained battery that is on trickle charge. If the recorder is located in a power house, a carry-over circuit can be operated from the station battery.

Translator-Computer

Translators are made to match the field tapes to the basic types of computer inputs—punched-card fed and ½-inch magnetic tape.

For a punched-card computer, the field-tape data is tabulated, one data track plus the time track at a time. The translator counts and stores the pulses for an interval and causes the connected card-punch machine to punch that interval pulse count in a three-column field on the card. Thus, 48 columns of the card carry data from 16 intervals so that six 80-column cards can handle the data for a 24-hour day of 15-minute intervals. The remaining 32 columns of the 80-column card carry customer identification, pulse constant, date, etc. In terms of today's computer speeds, the punched-card system is comparatively slow because the speed of trans-



1—Basic elements of the magnetic tape pulse recorder system required for demand billing and load study.

lation is limited by the punch machine. One translator, driving two key-punch machines, can translate a 30-day field tape in 14 minutes.

For a tape-fed computer, the raw field data is translated from the field tape to standard ½-inch computer tape in alpha-numeric code. This tape-to-tape system permits a considerable speed-up in data translation. In fact, three tracks of data can be translated in the same time as that given above for a single-track tape-to-card conversion.

With the new multiple-access computers (such as the IBM 360), a direct-entry translator is being planned which is basically a ¼-inch field-tape reader and amplifier that reads data from the field tape directly into computer storage.

System Capabilities

The overall capabilities of the magnetic tape recording system are demonstrated by the variety of measurement schemes that have been tried by utilities during two years of field testing. Several of the basic systems developed for data logging, system load studies, rate studies, or billing are listed in the table on p. 133. The simplest application is the case where the rate calls for kilowatt demand and kilowatt-hours only (System 1 in the table). A WR-2 recorder and single kilowatt-hour meter are required. This application will probably account for almost all of the WR-2 recorder installations.

One of the most common applications expected for four-track recorders is shown as System 2 in the table; three kilowatt-hour meters feed three tracks of a WR-4 recorder. This arrangement eliminates the need for a three-channel totalizer. In fact, even for a seven-meter totalizing application, conventional equipment (seven meters, a seven-channel electronic totalizer, and a chart or printing demand recorder) works out to be about 18 percent more expensive than the same seven meters feeding into two WR-4 recorders and a WR-2 recorder. Taking advantage of the computer, there is virtually no limit to the number of points possible to totalize. Even subtraction of one or more points is made easy. Another advantage of the tape recorder system over a totalizer is that pulse values need not be equal, as they must be when feeding a conventional totalizer. Thus, the highest pulse rate that the recorder can

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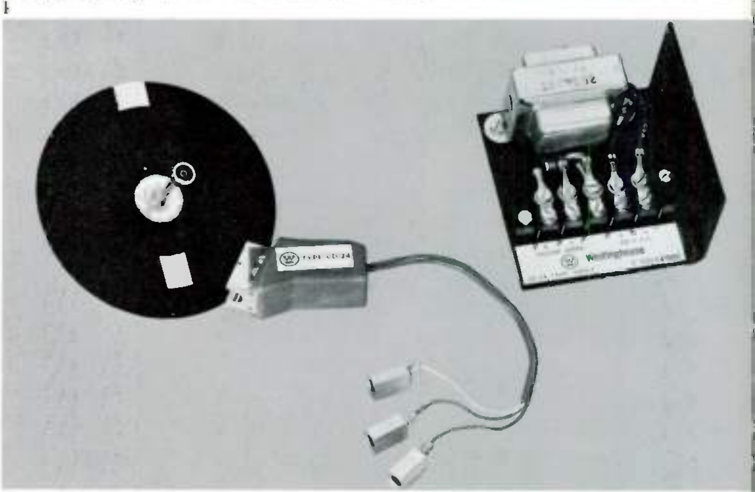

2

3, 4

1) Magnetic tape is contained in a cartridge to simplify loading and changing by servicemen. The WR-4 recorder on the left is in a surface-mounted case; on the right, a WR-2 recorder is shown in a flush-mounted case.

2) Photoelectric pulse initiators are capable of transmitting 2 to 24 pulses per disc revolution, depending on the type of meter. Shown here with the CD-24 photoelectric pulse initiator is the disc pattern for two pulses per revolution.

3) Tape-to-tape translator is used to transfer information from ¼-inch magnetic field tape to standard ½-inch computer tape.

4) All electronic circuitry for magnetic tape recorder is on plug-in printed-circuit board.

accept can be used on each meter so that pulse values can be kept to a minimum, as contrasted to a totalizer system where minimum pulse values are determined by the pulse value of the meter with the highest loading.

Many utilities have expressed interest in a tape recorder system where rates are based on kva demand, or kw demand and simultaneous kva demand. System 3 in the table is a method for accomplishing this with one WR-4 recorder, one kwh meter, a kvarh meter for leading power factors, and another kvarh meter for lagging power factors. The computer also can be programmed to calculate and print out both power factor and load factor.

System 4 is the same as System 3 except that if power factor is known to always be lagging (or if there is no concern for kva at leading power factors), only one WR-4 data track is needed for kvarh and the third track is available for other uses. In this case, volts-squared-hours is recorded on the third track for a substation metering application. A volts-squared-hour meter is essentially a single-phase meter with two potential coils (rather than one potential and one current coil as used in kilowatt-hour meters). One of the potential coils is lagged 90 degrees behind the other to provide the 90-degree flux displacement required to produce torque on the disc. Thus, the disc rotates at a speed proportional to volts squared. The computer can quickly unscramble this information and compute the average voltage and current over the interval. Similarly, an ampere-squared-hour meter is also available; it uses two current coils to produce disc rotation proportional to current squared.

System 5 in the table is similar to System 4 except that a "Q" meter has been substituted for the kvarh meter. A "Q" meter is similar to a varhour meter except that the meter potential is lagged only 60 degrees behind system voltage (rather than 90 degrees) so that "Q"-meter disc speed is zero at system 30 degrees leading power factor and builds up to maximum at 60 degrees lagging power factor. The 60-degree shift is obtained in the polyphase circuits simply by cross-phasing potential and current elements. The meter then measures EI Cos ($\theta-60°$), which is called "Q". The mathematical relationship between watts, vars, and "Q" can be expressed by the formula:

$$\text{Vars} = \frac{2\,Q - \text{Watts}}{\sqrt{3}}$$

The computer gets watts from one track and "Q" from another so that vars and kva can be calculated. Thus, the computer results are the same as for System 4 except that kva is obtained for power factors from 30 degrees leading to 60 degrees lagging rather than for just lagging power factors. Although 30 degrees leading to 60 degrees lagging should take care of 99 percent of the system applications, some applications may have greater power factor limits. In these cases, a second tape recorder and two reactive kvarh meters will be required.

From a capability standpoint, System 6 is one of the most interesting examples listed. This system does a complete net interchange metering job with one WR-4 recorder and three meters. All of the information obtained from System 5 is available except for average voltage and current, and total kvarh and kwh flow for power factors from 30 degrees leading to 60

Metering Schemes for Recording Data for Load Study and Billing Computation

Tape System	*Recorder*	*Meter Number and Data Track Number*				*Computer Net Result Basis for Billing and Information for System Study*	
		M1-DT1	*M2-DT2*	*M3-DT3*	*DT4*		
1	WR-2	KWH	Time	—	—	KW and KWH	
2	WR-4	KWH	KWH	KWH	Time	Totalized and/or individual KWH and KW	
3	WR-4	KWH	RKVAH Lead	RKVAH Lag	Time	KWH, RKVAH, KVAH, KW, RKVA, KVA PF, Load Factor	
4	WR-4	KWH	RKVAH Lag	V^2H	Time	KWH, RKVAH, KVAH, KW, RKVA, KVA PF, Load Factor Volts (avg), Amps (avg)	Lagging PF only
5	WR-4	KWH	Q	V^2H	Time	KWH, RKVAH, KVAH, KW, RKVA, KVA PF, Load Factor Volts (avg), Amps (avg)	For PF from 30° leading to 60° lagging
6	WR-4	KWH In	KWH Out	Q	Time	Net Interchange – KWH, RKVAH, KVA KW, RKVA, KVA PF, Load Factor	For PF from 30° lead to 60° lag, power flow either direction
7	WR-4	KWH Phase A	KWH Phase B	KWH Phase C	Time	KW demand, KWH for transformer loading analysis	
8	WR-4	Lb Coal	Generator KWH	Station KWH	Time	Generator Efficiency Station Efficiency, Auxiliary Load	

In all systems, the data shown can also be obtained for multiple meter systems, including total KWH, simultaneous system demand, etc.

degrees lagging in either direction is obtained. Kva and kw in and out demand are also produced by the computer. For purposes of kva calculation, the computer is programmed to ignore any interval in which power flows in both directions since in these intervals "Q" pulses cannot be associated with corresponding watthour pulses. However, it is unlikely that a peak will occur in such an interval so this should pose no problem. If it does, a second "Q" meter can be installed and the pulses recorded on a second magnetic tape recorder, probably a WR-2.

Systems 7 and 8 have no billing applications, but illustrate further possibilities in the area of overall system study.

Automatic Billing

In a normal billing situation, a printout would not be required during bill preparation except for those customers who want demand data along with their bills (these are the people who now receive recorder charts). In the event of a question over a bill, the original computer entry medium can be rerun to produce a printout, along with any other information that may be desired.

A typical computer calculation for a simple two-meter totalizing situation is illustrated by the printout shown in Fig. 2. The computer begins totalizing with the first interval in which both recorder data tracks carry pulses. With two meters feeding two tracks of a single WR-4 recorder, selection of the first interval by the computer is automatic; if two meters feed two different tapes, the computer must be programmed to select data only from intervals where both recorders are in operation. The leftover data would be stored until next month, retrieved, and added to next month's record.

In this example, the first interval in which both recorders were in operation ends at 10:30 A.M. on December 17. Total pulse count from both meters for this interval was 63. Totalizing and printing proceeds until the last interval in which both recorders were operating—10:30 A.M. on January 19, in which the totalized interval count was 129. Total pulses are then computed for the month—120,956. The pulse constant, 1.2 kwh per pulse, is applied to obtain total kilowatt-hours for the period, 145,147 kilowatt-hours.

In this case, the pulse constant (1.2 kwh per pulse) is the same for both meters. It can be different, and then requires another step for the computer to arrive at totalized kilowatt-hours.

The data read from the meter registers by the serviceman is also entered into the computer at the same time that the tape data is entered. The computer is programmed to obtain the total kilowatt-hours from these register readings (Fig. 3) and compare this figure against the total kilowatt-hours computed from pulse count. Thus, total kilowatt-hours obtained by meter register readings is 144,960—total calculated from recorded pulses was 145,147 for a difference of 187 kilowatt-hours. Since this difference is smaller than the largest kilowatt-hour meter constant (in this case, 240 kilowatt-hours as determined by current and potential instrument transformer ratios), the difference is acceptable and the computer proceeds to calculate and print out demand data in accordance with the rate structure requirements. A typical printout of this type of data is shown in Fig. 4.

The computer's final step would be to prepare a bill based on the figures it had calculated from tape data and the rate structure for the particular customer. This simple billing example illustrates the versatility of the magnetic tape recorder system. The computer can be easily programmed to analyze this same data and print out the information in a form convenient for rate studies, system load analysis, etc. Typical examples are a daily peak and monthly peak summary (Fig. 5), and hourly demands of the peak two days (Fig. 6).

Permanent Records—Most recording demand customers are probably already familiar with computer-prepared data. Thus far, utilities that have tried magnetic-tape billing in field trials have not indicated problems with their customers when charts were replaced by computer printouts. Experience thus far with utility commissions and legal advisors also indicates that ½-inch computer tape or punched cards will be acceptable for permanent records. Of course, the original programs used to process the cards or tape should be maintained. In the case of the multiple-access system where no computer tape or cards are prepared, a printout will probably be required for permanent records.

Records existing solely in the form of computer tape or printout are becoming completely acceptable in other areas to most regulatory and taxing authorities. Both computer tapes and printouts have been accepted as legal evidence by the courts.

Field Testing Experience

It was realized early in the design of the tape recording system that while the equipment could be made to work technically, many other factors were involved—reactions of the customer to a system in which the pulses being recorded cannot be seen, the handling of magnetic tapes by servicemen, and the compatibility of the tape-recording equipment with the various data-processing equipments that would be needed. To get the necessary field experience, Westinghouse made over 100 magnetic tape recorders and distributed them to utilities[1] who

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[1] The utilities that participated in the cooperative study were: Potomac Edison Company, West Penn Power Company, Commonwealth Edison Company, Florida Power Corporation, United Illuminating, Pacific Gas and Electric Company, Long Island Lighting Company, Ohio Power Company, Tennessee Valley Authority, and the operating companies of American Electric Power System—Appalachian Power Company, Indiana & Michigan Electric Company, Kentucky Power Company, Ohio Power Company, and Wheeling Power Company.

2—**Typical computer printout** for a simple one-month totalizing operation.

3—**Summary of computer comparison** of total kwh obtained from pulse count and from meter-register readings.

4—**Summary of demand data** determined by computer to satisfy rate structure requirements for billing.

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ACCOUNT NUMBER  09114632877   DEMAND METER NC.  6486502   START - DEC 17 64   1030 AM   END    - JAN 19 65   1017 AM

  1/2 HOUR   DEC     DEC     DEC     DEC     DEC     DEC     DEC     DEC     DEC     DE       JAN     JAN     JAN     JAN     JAN     JAN     JAN     JAN     JAN
   ENDING     17      18      19      20      21      22      23      24      25      :        11      12      13      14      15      16      17      18      19

AM   1230             0041    0036    0027    0027    0028    0026    0026    0023    00       0036    0041    0042    0042    0043    0035    0032    0035    0051
        1             0039    0034    0026    0026    0028    0026    0026    0023    00       0039    0040    0042    0039    0040    0034    0032    0039    0047
      130             0038    0032    0026    0030    0029    0026    0026    0023    0        0038    0039    0039    0040    0043    0034    0033    0039    0046
        2             0038    0034    0026    0026    0028    0025    0026    0022    '        0040    0039    0041    0040    0042    0033    0032    0039    0047
      230             0038    0033    0026    0027    0028    0026    0027    0023             0038    0038    0040    0039    0043    0034    0032    0041    0046
        3             0055    0033    0027    0026    0029    0026    0025    0023          ,  0039    0038    0039    0039    0042    0034    C032    0039    0049
      330             0076    0034    0026    0027    0029    0025    0027    0022          0  0063    0040    0048    0046    0043    0034    0033    0053    0056
        4             0074    0033    0026    0027    0029    0025    0028    0023         29  0074    0072    0079    0071    0083    0033    0032    0077    0089
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        6             0113    0035    0026    0028    0029    0036    0034    0C         0029  0143    0130    0146    0134    0153    0035    0032    0142    0161
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        8             0219    0066    0026    0057    0066    0062    0065    0022         28  0236    0226    0232    0236    0240    0067    0032    0236    0238
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        9             0185    0070    0026    0062    0072    0070    0068    0021    (        0222    0222    0207    0234    0237    0076    0031    0231    0245
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       10             0181    0068    0026    0067    0072    0071    0068    0022    00       0230    0230    0213    0242    0244    0067    0031    0240    0246
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       11     0225    0161    0057    0026    0073    0069    0087    0067    0023    004      0226    0230    0217    0232    0245    0066    C031    0234
     1130     0221    0144    0057    0027    0070    0070    0075    0067    0020    00       0212    0214    0207    0220    0235    0063    0031    0224
NOON   12     0199    0153    0062    0027    0069    0065    0079    0068    0022    0C       0218    0212    0187    0226    0222    0062    0032    0207
PM   1230     0206    0166    0063    0026    0058    0067    0082    0063    0022    0        0227    0235    0201    0240    0244    0062    0031    0231
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      930     0071    0063    0027    0028    0037    0036    0034    0033    C          C029  0069    0077    0075    0079    0067    0034    0032    0072
       10     0070    0062    0026    0026    0037    0036    0034    0025               0029  0069    0077    0075    0078    0067    0032    0032    0075
     1030     0067    0049    0027    0028    0036    0033    0035    0024               0028  0063    0074    0067    0073    0061    0032    0031    0071
       11     0069    0040    0026    0027    0036    0034    0034    002         29     0029  0067    0076    0069    0074    0065    0033    C032    0072
     1130     0062    0036    0027    0027    0036    0032    0031    00        0028     C029  0058    0064    0059    0065    0054    0032    0031    0068
MIDN   12     0050    0036    0026    0027    0030    0025    0026    0C        0029     0030  0047    0047    0046    0048    0042    0032    0033    0059
DLY. TL.     3,782   5,222   1,931   1,275   2,218   2,286   2,335   2,(      2,028    1,376 6,542   6,640   6,552   6,714   6,705   2,135   1,528   6,759   2,829
                                                                                   TOTAL PULSES        120,956            CCNSTANT      1.20            KWHRS         145,147
```

```
PULSE TOTAL FOR TRACK #1  S      81,202
PULSE TOTAL FOR TRACK #2  S      39,754
PULSE TOTAL FOR TRACK #3  S

THE FOLLOWING WATTHOUR METERS ARE CONNECTED TO DEMAND METER NUMBER 6486502

            WHM NUMBER I000454                    START READING    0789
                                                  FINAL READING    1194
                                                  DIFFERENCE        405
                                                  WHM CCNSTANT   000240
                                            DIFF. X CCNST        97,200

            WHM NUMBER I000247                    START READING    1405
                                                  FINAL READING    1803
                                                  DIFFERENCE        398
                                                  WHM CCNSTANT   000120
                                            DIFF. X CCNST        47,760

                       TOTAL KWHRS OF WH METERS            144,960

                       KWHRS OF DEMAND METER               145,147   DMC KWHRS LARGER THAN WH KWHRS

                       DIFFERENCE                              187-
```

```
                                                                 KILO-        DATE
                                                                 WATTS     MON DY YR   TIME

              1. FOUR HIGHEST DEMANCS.                           609.60    JAN 08 65   0230 PM
                                                                 602.40    JAN 07 65   1230 PM
                                                                 600.00    JAN 15 65   1030 AM
                                                                 597.60    JAN 06 65   1230 PM

              2. FOUR HIGHEST DAYTIME DEMANDS. RIDER 22          609.60    JAN 08 65   0230 PM
                                                                 604.80    JAN 08 65   0200 PM
                                                                 602.40    JAN 07 65   1230 PM
                                                                 600.00    JAN 15 65   1030 AM

              3. FOUR HIGHEST DEMANDS IN THE PEAK PERIOC.        355.20    JAN 07 65   0500 PM
                                                                 350.40    JAN 06 65   0530 PM
                                                                 345.60    JAN 06 65   0630 PM
                                                                 343.20    JAN 06 65   0500 PM

              4. FOUR HIGHEST DAYTIME DEMANDS. RATE 13           609.60    JAN 08 65   0230 PM
                                                                 604.80    JAN 08 65   0200 PM
                                                                 602.40    JAN 07 65   1230 PM
                                                                 600.00    JAN 15 65   1030 AM

              5. FOUR HIGHEST NIGHT DEMANDS. RIDER 22            590.40    JAN 08 65   0830 AM
                                                                 576.00    JAN 08 65   0800 AM
                                                                 576.00    JAN 15 65   0800 AM
                                                                 571.20    JAN 07 65   0800 AM

              6. HIGHEST DEMAND - DUSK TO DAWN.                  518.40    JAN 08 65   0700 AM

SELECTION OF HIGHS FOR THIS ACCOUNT WERE MADE DURING THE PERIOD BETWEEN 64-12-17 1030 AM   AND 65-01-19 1030 AM   USING THE
FOLLOWING DEMAND METERS
                    6486502
```

had shown greatest interest in tape recording. In this cooperative program, which began in 1963, the utilities tried the units on their systems, and made suggestions as to how the equipment could best be applied or improved.

By mid-1965, at least a year's service experience had been gained with almost all of the trial recorder applications, which include most of those listed in the table. From this experience, a number of suggested improvements were incorporated into the overall system. For example, the volts-squared-hour meter and the ampere-squared-hour meter were developed so that the utilities could make more comprehensive system studies with magnetic tape recorders. This kind of information can help system planners size transformers, circuit conductors, breakers, and fuses.

The feasibility studies also demonstrated the practicability of using magnetic tape recorders for demand billing of industrial and large commercial customers. Several utilities are now planning to use both WR-2 and WR-4 recorders for this purpose. In many instances, the four-track units will replace totalizers as well as recording chart meters.

The magnetic tape recording system equipment has now gone through rigorous shop testing and field testing. From the original load survey magnetic tape recorder, first designed as a low-cost device for residential load rate studies, an automated system has now emerged that can perform intensive system studies and also provide the high level of reliability and accuracy needed to perform the complete demand billing cycle.

Westinghouse ENGINEER
September 1965

5—Daily peak and monthly peak summary can be extracted by computer from power usage data.

WEST SUB. OCT. 1 - OCT. 24 LOAD STUDY

DAILY SUMMARY

DAY	HOUR	MVA	MW	MVAR	P.F.	VOLTS	AMPS	L.F.	TOTAL MWH
1	19	14.75	14.37	3.33	.9741	2400	2048	.4804	165.75
2	19	14.84	14.47	3.27	.9753	2400	2061	.7849	272.67
3	19	14.46	14.15	3.00	.9782	2410	2000	.8008	271.97
4	18	10.71	10.55	1.84	.9850	2460	1451	.8000	202.57
5	19	9.16	9.10	1.09	.9928	2470	1236	.7700	168.17
6	19	14.71	14.40	3.03	.9785	2400	2043	.7625	263.55
7	18	14.79	14.40	3.40	.9731	2400	2054	.8045	278.05
8	19	14.91	14.52	3.39	.9738	2400	2070	.8032	280.00
9	19	14.57	14.15	3.49	.9708	2400	2023	.8184	277.95
10	19	17.42	16.97	3.94	.9740	2370	2450	.7257	295.67
11	18	12.66	12.55	1.73	.9906	2440	1729	.7924	238.70
12	19	11.32	11.25	1.32	.9931	2450	1540	.7392	199.60
13	18	17.20	16.75	3.92	.9736	2370	2419	.7462	300.00
14	18	17.41	16.87	4.31	.9688	2370	2448	.7350	297.67
15	18	17.52	17.00	4.27	.9698	2350	2485	.7318	298.60
16	18	16.20	15.80	3.60	.9748	2380	2268	.7552	286.37
17	18	16.26	15.85	3.63	.9746	2380	2277	.7657	291.30
18	18	13.19	12.97	2.41	.9831	2430	1809	.7613	237.07
19	18	10.48	10.30	1.96	.9823	2460	1420	.7620	188.37
20	18	16.61	16.20	3.69	.9749	2380	2326	.7050	274.12
21	18	16.38	16.02	3.42	.9779	2380	2294	.7475	287.50
22	17	16.87	16.40	3.98	.9717	2370	2372	.7482	294.50
23	17	16.67	16.10	4.35	.9652	2370	2344	.7774	300.42
24	10	13.64	13.17	3.56	.9652	2430	1871	.3756	118.77

MONTHLY SUMMARY

	DAY	HOUR	MVA	VOLTS	AMPS	MW	MVAR	P.F.	L.F.
PEAK MVA HOUR	15	18	17.52	2350	2485	17.00	4.27	.9698	.7318
MAX MVAR HOUR	15	17	15.48	2380	2268	14.72	4.80	.9506	
MIN MVAR HOUR	24	12	2.97	2470	400	2.62	-1.40	.8823	

TOTAL MWHR FOR MONTH - 6089.40

MONTHLY LOAD FACTOR - .6218

6—Hourly demands of the peak days also provide useful information for system load analysis.

EAST SUB. DEC. 1 - DEC. 31, 1963

DAY	HOUR	MVA	MW	MVAR	P.F.
11	1	21.98	21.80	2.82	.9916
11	2	19.87	19.80	1.67	.9964
11	3	18.78	18.75	1.18	.9980
11	4	17.05	17.05	.43	.9996
11	5	15.90	15.90	.28	.9998
11	6	15.45	15.45	.37	.9997
11	7	17.82	17.75	1.58	.9960
11	8	22.70	22.25	4.53	.9798
11	9	26.59	25.95	5.80	.9759
11	10	28.34	27.55	6.66	.9719
11	11	30.19	29.20	7.67	.9671
11	12	29.87	29.00	7.15	.9708
11	13	29.56	28.80	6.69	.9740
11	14	30.31	29.30	7.79	.9663
11	15	29.82	28.75	7.93	.9639
11	16	29.37	28.45	7.30	.9685
11	17	31.58	30.80	6.98	.9752
11	18	35.50	34.65	7.76	.9757
11	19	34.37	33.55	7.47	.9760
11	20	33.63	32.85	7.24	.9765
11	21	31.76	31.10	6.46	.9790
11	22	29.39	28.80	5.88	.9797
11	23	25.96	25.50	4.90	.9819
11	24	23.91	23.60	3.86	.9868
12	1	22.46	22.25	3.08	.9905
12	2	20.05	19.95	2.04	.9947
12	3	18.60	18.55	1.41	.9971
12	4	16.75	16.75	.54	.9994
12	5	15.40	15.40	.46	.9995
12	6	14.90	14.90	.51	.9993
12	7	15.79	15.75	1.18	.9971
12	8	18.35	18.15	2.74	.9887
12	9	20.73	20.40	3.69	.9839
12	10	22.43	22.00	4.38	.9806
12	11	24.02	23.60	4.50	.9822
12	12	23.87	23.55	3.95	.9861
12	13	23.05	22.80	3.40	.9890
12	14	22.63	22.35	3.55	.9876
12	15	21.94	21.70	3.29	.9886
12	16	21.53	21.35	2.80	.9915
12	17	24.57	24.35	3.31	.9908
12	18	29.52	29.20	4.38	.9888
12	19	27.59	27.30	4.04	.9892
12	20	26.06	25.80	3.69	.9898
12	21	24.69	24.45	3.49	.9899
12	22	23.45	23.25	3.08	.9912
12	23	21.62	21.50	2.30	.9942
12	24	19.97	19.90	1.73	.9962

A Numerical Positioning Control System Based on Integrated Circuits

by A. T. Bacheler

Use of molecular-electronic integrated circuits drastically reduces the number of components and solder connections in the control system, thereby reducing probability of circuit failures.

A simple two-axis numerical positioning system for machine-tool control, built largely from integrated circuits, has been developed, packaged in an industrial configuration, and applied successfully to a multiple-spindle turret drill. The control system has sufficient tool-selection capacity for most tool-changing machines, and it can be readily programmed manually or with computer assistance. Applications for the initial system include single- and multiple-spindle two-axis drills, single-tool and turret automatic punches, and small milling machines.

The primary design objectives were high reliability—much higher than that of other numerical control systems—combined with low cost and flexibility. The reliability and cost requirements were met by building the new control around integrated circuits. These integrated circuits have demonstrated reliability, in extensive test programs, approaching that of individual transistors. (*See Monolithic Integrated Circuits*, page 139.) Moreover, their use reduces the number of components and solder connections in a circuit dramatically and thus greatly reduces the probability of circuit failures.

The cost of certain integrated circuits, including those used in this control system, has fallen within the past year to the point where they compete with equivalent circuits assembled from conventional elements. Further cost reductions are likely, while the cost of conventional components probably will stay about the same.

Other advantages of using integrated circuits stem from their small size, low power consumption, and fast switching rate. No cabinet ventilation is required, and the complete control system can fit into a small enclosure. In some applications, the control cabinet can be mounted on the wall or on the machine, taking no floor space whatever. Fast switching permits time sharing of circuits in the system, with consequent reduction of the number of circuits required.

The overall design of the system is such that it is flexible in application. Pre-engineered modifications provide a number of options and permit easy expansion of capacity to handle a wide range of requirements.

The control development was undertaken jointly by two Westinghouse groups. The Aerospace Division of the Defense and Space Center at Baltimore developed the new circuits necessary to take advantage of the molecular-electronic device characteristics. Liberal use was made of the Division's experience in advanced data-handling techniques, in the use of molecular-electronic devices, and in advanced circuit and system design. The Numerical Control Department at Buffalo contributed its practical experience with application and installation of solid-state and other numerical controls.

This new numerical control development was first applied in a two-axis control for simple drills or punches. It was designed, packaged, and applied to a Burgmaster 1DHT turret drill in the laboratory. The control-machine combination was then tested to confirm the reliability of the equipment in operation over a wide range of temperatures and voltage-supply variations and in the presence of electrical noise.

Integrated-Circuit Application

The diode-transistor-logic NAND (DTL NAND) was selected as the basic integrated-circuit logic element largely because all the needed logic functions can be constructed from it. Another reason is that this was the first integrated-circuit logic element developed, so it has the longest reliability history. Furthermore, production yields are high, and the present off-the-shelf availability indicates a continuing reliable supply.

A NAND is a digital circuit with a number of inputs and a common output that may serve a number of loads, including the inputs to other NANDs. It accepts and produces signals characterized by only two states, which are assigned the values *one* and *zero*. The *one* is a positive signal of about four or five volts; the *zero* is a lower voltage, near zero volts. Logically, the NAND is the inversion or negation of an AND.

The basic NAND circuit used in the new control system is diagrammed in Fig. 1a. If all inputs are energized with *one* signals, the base of the transistor is positive with respect to the emitter, and current can flow from collector to emitter and ground. Thus, any NAND inputs connected to the output are grounded, and the voltage output is close to zero. If any one or more of the inputs is grounded (has a *zero* signal), the basic drive of the transistor is removed and the transistor does not conduct, thereby causing a *one* signal level on the inputs to NANDs connected to the output.

The molecular circuits used in the new control consist of only three NAND configurations. These building blocks are the single NAND gate with four inputs and a node (Fig. 1a), a dual NAND having two separate NANDs each provided with three inputs (Fig. 1b), and a reset-set flipflop consisting of two four-input NANDs internally cross-coupled to provide three inputs on the reset side and three on the set side (Fig. 1c).

For comparison purposes, Fig. 1c shows the solder connections that would have to be made if that circuit were built from individual components soldered together. The integrated circuit, mounted in a TO-5 can, is complete with two internal thermally bonded connections for each lead on the header. These connections are orders of magnitude more reliable than are solder connections. Ten external solder connections, at most, are required to put the device into a circuit; an individual-component assembly would require the same number of external connections and, in addition, 32 internal solder connections. Thus, use of the integrated circuit cuts the number of solder connections in the completed circuit on a printed

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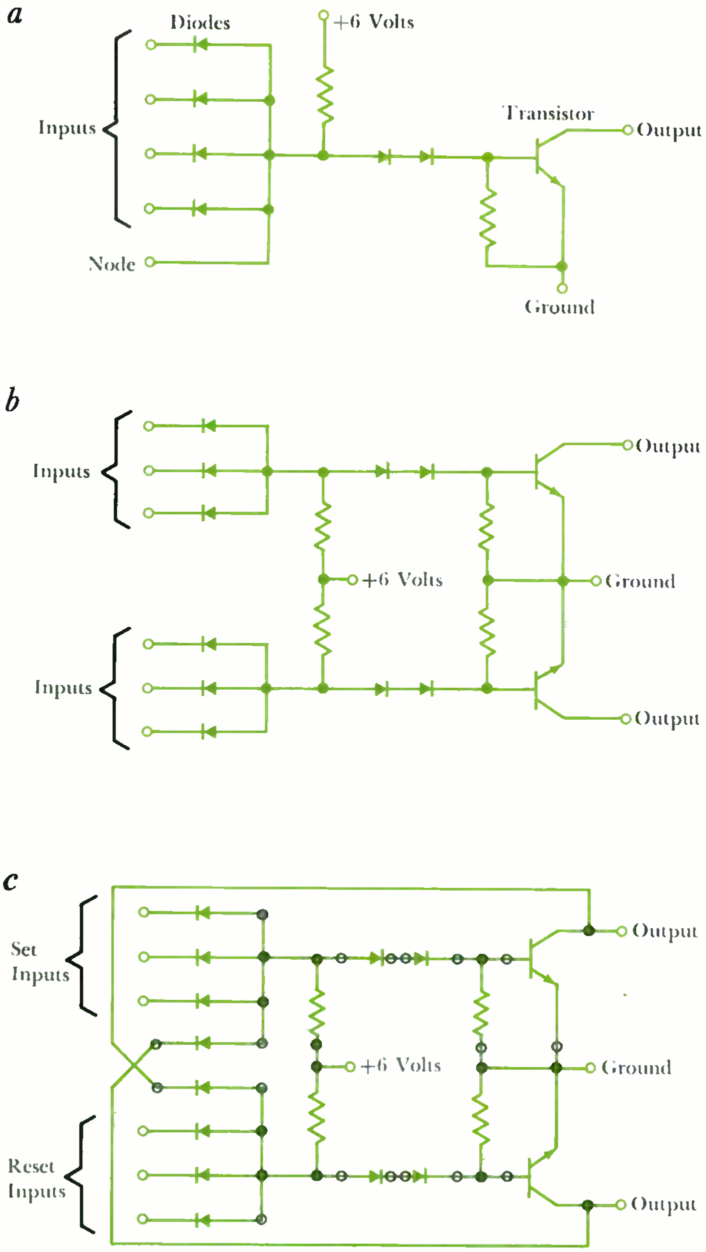

1—Integrated-circuit NAND devices used in the control logic are represented by these equivalent-circuit diagrams. (a) The basic circuit is a single NAND gate with four inputs and a node, or tie point, for additional inputs through external diodes. The remaining two are (b) a dual NAND and (c) a reset-set flipflop. Black circles in (c) indicate the 32 internal solder connections that would have to be made if the circuit were assembled from individual conventional components; the integrated-circuit devices, in contrast, have no internal connections to be soldered. The dramatic reduction in the number of components and solder connections greatly improves the potential reliability of systems based on integrated circuits.

circuit board to less than a fourth of that required with individual components. This great reduction in the number of solder connections reduces the likelihood of a connection failure in the control system in a given period of time and consequently enhances the potential reliability.

A digital position measuring system was designed, with a pulse generator as the feedback device. The relatively high speed of the integrated circuits permitted use of a serial system for processing data. (Typical average switching time is 23 nanoseconds at room temperature—two orders of magnitude faster than that of the previously used transistors.) The use of this serial system allowed maximum use of time-sharing, producing a system with a relatively small number of components. An older generation of solid-state control required 6500 circuit elements for a two-axis machine; the new control performs the same tasks with fewer than 250 molecular circuits and about the same number of conventional elements.

Thus, the use of molecular circuits and the serial data-processing system reduce the number of components and the number of solder connections in the system by an order of magnitude. The result is a large improvement in potential reliability. Moreover, the choice of the feedback device, serial logic, and time sharing make for low system cost, one of the design objectives.

The small size of the molecular circuits facilitates packaging the control in a minimum of space (a small wall-mounted box for some applications). Moreover, the molecular circuits operate at lower power levels than do conventional logic systems, and this lower power requirement also saves space and reduces the need for heat dissipation. Furthermore, since the basic semiconductor material of the integrated circuits is silicon, the circuits can tolerate considerably higher cabinet temperatures than germanium devices can. Both factors permitted design of a cabinet that does not require external ventilation for the logic portion—the logic section is totally enclosed and consequently free from accumulation of dirt and contaminants. The total logic for a two-axis system with 80 auxiliary functions can be packaged in a volume 18 by 12 by 8 inches.

Capabilities

The control has two numerically controlled positioning axes, permanently designated x and y. Maximum length of each axis is 524,287 units (19 binary bits of position information, or $2^{19}-1$). If the minimum unit of length chosen is 0.001 inch, the maximum axis command is 524.287 inches. The system is perfectly capable of handling units of other value, such as 0.0001 inch (in which case the maximum axis command would be 52.4287 inches). Since both positive and negative commands can be programmed, the total maximum axis motion is double these values.

The maximum rate of information handling in the logic is 12,500 pulses per second, regularly distributed. This allows, assuming normal variation and distribution of pulses from the pulse generator, at least 6000 pulses per second per axis; with a pulse value of 0.001 inch, a maximum positioning speed of 360 inches per minute results. However, the maximum permissible rate of information handling depends not only on the logic itself but also on the characteristics of the feedback transducers used for particular applications.

The system permits simultaneous positioning of both axis motions. Final positioning of each axis is from one direction only in the normal positioning mode, with a small amount of intentional overshoot provided to insure taking up backlash always in the same direction.

The positioning system has a relocatable zero on each axis; that is, the zero reference point can be moved from its normal place near a corner of the table to any location that may be more convenient in a particular operation.

Numerical data is introduced from standard one-inch perforated tape read on a mechanical tape reader that has a rated reading speed of 25 characters per second. Programming of dimension commands is in absolute dimensions with respect to a zero reference location, with a minus sign used to designate dimensions on the negative side of the zero reference point and the absence of a minus sign to designate dimensions on the positive side. A parity check is provided for information read from the tape. A nonparity indication stops the reader, lights an indicator telling the operator that a reading error has occurred, inhibits machine motion, and requires the operator to reset the tape and restart the cycle.

The basic system has provision for the addition of miscellaneous functions coded m00 to m19, with m00 (program stop) permanently committed. The other codes are uncommitted and can be used in programming such machine functions as spindle direction, spindle off, coolant on and off, tool change, and milling on and off. The miscellaneous function

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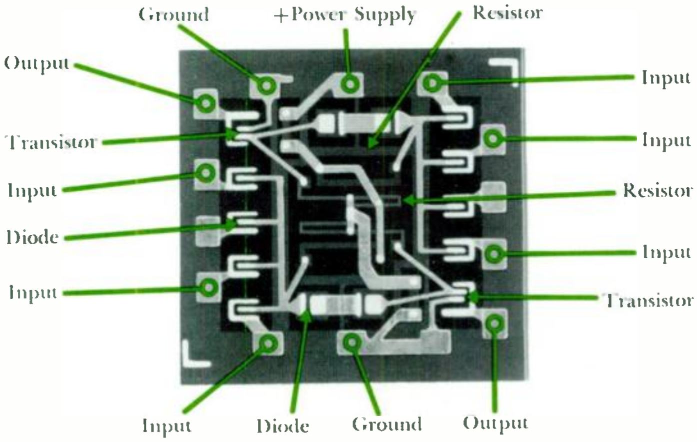
Monolithic Integrated Circuits, also called molecular circuits, are complete electrical circuits composed of active and passive components such as transistors, diodes, and resistors. These components are formed in a single tiny piece of silicon and integrally interconnected to perform a function. The circuits are tested and then packaged in flat packages or in cans with the necessary external connections.

While industrial use of integrated circuits has just begun, there is a firm foundation of development and use in military applications going back to 1959. Military electronic systems were growing in complexity so rapidly that gains in reliability achieved by major quality-control work were being offset by increased system complexity. Integrated circuits were developed under U.S. Air Force sponsorship as a promising solution. They have been used successfully in guidance systems for the *Minuteman* missile, in systems for the *Saturn* rocket, in data processors, and in a number of other systems.

The device failure rate determined by the integrated-circuit industry in 1964 for integrated circuits of moderate complexity, such as the dual NAND gate, was approximately 0.04 percent per thousand hours at rated temperature and power. (See reference 2 in the bibliography, below.) Failure rates are expected to diminish, approaching as a limit the rate for individual transistors, as a result of continuing improvements in control of the complex manufacturing processes. Predicted failure rates for the next few years are:

Time of Production	*Predicted Failure Rate (per thousand hours)*
Mid-1965	0.01 percent
Mid-1966	0.003 percent
Mid-1967	0.001 percent



An integrated circuit, enlarged about 34 times here, is formed in a single piece of silicon. This one is a dual NAND gate.

For comparison purposes, an estimate of failure rate for an equivalent dual NAND circuit made up of individual components can be made by adding the failure rates for the individual components (since failure of one component causes failure of the system). The approximate figures are:

Device	*Number Used*	*Individual Failure Rate (per thousand hours)*	*Total Failure Rate (per thousand hours)*
Transistor	2	0.02 percent	0.04 percent
Diode	10	0.02 percent	0.20 percent
Resistor	4	0.001 percent	0.004 percent
			0.244 percent

The total failure rate for the equivalent circuit is about six times that (0.04 percent) for an integrated-circuit NAND gate produced in 1964.

Integrated-circuit technology has matured much faster than did transistor technology, because integrated circuits are based on the foundation of such existing semiconductor technologies as high-precision photography, diffusion technology, and vacuum evaporation techniques. Thus, when Westinghouse decided to develop the new numerical positioning control, integrated circuits were sufficiently mature to be used as basic building blocks. The Westinghouse Molecular Electronics Division is a developer and supplier of the integrated circuits.

Bibliography:
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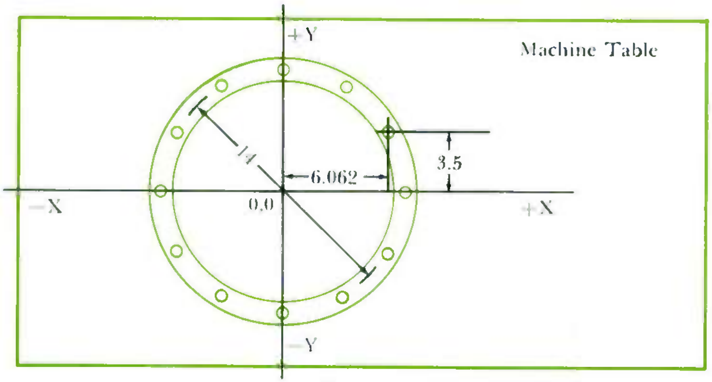


Program

Hole 1	X+7000	Y 0		EOB
2	X+6062	Y+3500		EOB
3	X+3500	Y+6062		EOB
4	X 0	Y+7000		EOB
5	X−3500	Y+6062		EOB
6	X−6062	Y+3500		EOB
7	X−7000	Y 0		EOB
8	X−6062	Y−3500		EOB
9	X−3500	Y−6062		EOB
10	X 0	Y−7000		EOB
11	X+3500	Y−6062		EOB
12	X+6062	Y−3500	m00	EOB

2—**Sample machine-tool control program** illustrates the advantage of positive and negative programming and relocatable zero when machining a symmetrical part. To program a series of 12 holes equally spaced on a 14-inch bolt circle, the zero reference position is located at the center of the circle and the locations of the holes in one quadrant are calculated. These dimensions and the proper signs then locate the remaining holes. ("EOB" stands for "end of block," and m00 indicates program stop.)

outputs are relay contact closures, with optional selection of momentary closure or maintained closure.

Also available as options are the addition of as many as 20 feed, speed, and tool functions. These outputs are relay contact closures that are maintained until cancelled by another selection. The selection of binary-coded decimal combination or individual signal outputs is available.

Programming is quite simple and can be done manually or with computer assistance. All commands are programmed in the word-address format, in which commands are prefixed by letter address characters and any words not required are omitted from a program block. The combination of positive and negative programming and relocatable zero simplifies the programming of symmetrical operations, such as a circle of bolt holes. With zero located at the center of symmetry and dimensions calculated for one quadrant of holes, the program for the remaining quadrants requires only the use of the proper sign with the dimensions already calculated (Fig. 2).

The numerical control package includes the operator's controls, tape reader, numerical control logic, output relays for auxiliary functions, and servo motor power supplies. Three basic modes of operation are provided in the control: automatic, single-cycle, and manual. Addition of manual data input from dials is optional.

In the automatic mode, machine operation is under the control of the tape program, once the program is initiated by the operator, and continues so until it is stopped by the operator or by a program stop. This is the normal mode of operation. Single-cycle operation is like the automatic mode except that the reading of each new block of tape commands must be initiated by the operator after the previous commands and machining cycle are completed. In the manual mode, the machine is operated at various jogging rates with spring-return switches; this mode is useful for setup and calibration. When the option of manual data input is supplied, numerical data similar to that read from tape can be introduced with data switches to initiate a single cycle of operation.

An optional milling mode permits straight-cut machining within the capabilities of the axis drives and the machine spindle.

The standard control cabinet is floor-mounted, but the option of a smaller wall- or machine-mounted cabinet is provided for use where space is limited. (A system has been packaged in a box 30 by 22 by 16 inches.) Another option is the use of a faster tape reader than the standard reader.

Components of the system are readily accessible for ease of maintenance. Test points are provided on the printed circuit cards for normal tests, most of which can be completed with test tapes. The clock system inherently provides reference times for checking the presence of signals.

Digital Positioning Control System

The serial digital positioning control system was selected to take advantage of the very short switching time of integrated circuits and to minimize the number of circuit components by time sharing (Fig. 3). In essence, the system compares a position command number read from a tape with a position feedback number. An error detector produces an error signal by subtraction of these two numbers, and the magnitude and sign of the error are used to command the axis positioning servo to drive in the direction that reduces the error to zero. For convenience and reliability in processing, all numbers are converted to and handled in binary form.

A serial system processes information one bit at a time in sequence, determining the significance of each bit by its time of occurrence at a single point in the system. (In contrast, in a *parallel* system of data processing, all bits of a number exist and can be detected at a given time; their significance is determined by bit location.)

In this system, the numbers representing command and position information are circulated by introducing them one bit at a time into a bit storage device. The bits of each number appear in the same order later at the output as a series of pulses. Because bits are handled serially at a rate well within the capabilities of the integrated circuits, much less hardware is required than would be required by a parallel system.

A numerical significance is assigned to each bit of a number by storing the first bit at the same time that a counter is started and following it with the succeeding bits as the counter is pulsed from a clock oscillator—one bit per pulse. The number in the counter identifies the bit being entered. The counter is made to reset and start over immediately after the last bit is entered; at that time the first bit is captured at the output and re-entered, the succeeding bits following in order. Thus, the number can be continuously recirculated.

Position information is generated from the output pulses of a pulse generator on the machine member. Since each pulse is equivalent to a unit of distance, 0.001 inch for example, motion is measured from a reference point on the machine slide (where the position feedback number is initially set to zero) by counting pulses. Each time the machine moves enough to cause the pulse generator to change state, one bit is added to (or subtracted from) the circulating position feedback number. (A bit is added for positive motion, subtracted for negative motion.) Since the number is being circulated continuously, there is only one proper time for this new bit to be added or subtracted. It must be introduced during Bit No. 1 time for the respective axis word when the least significant bit is being processed. The pulse from the pulse generator is stored in a memory until the next Bit No. 1 time occurs for that axis, and then it is processed. The memory is reset to wait for the next pulse.

Command numbers are stored similarly. This information, however, is changed only when it is desired to replace it with new commands. The old information is allowed to propagate out before new information is introduced.

Auxiliary function commands for feed, spindle speed, and tool selection are decoded directly from the tape and used to operate output relays. They are canceled or changed by the reading of new commands. The miscellaneous functions, such as starting and stopping the spindle, are handled in a similar manner or are canceled by completion of a command.

Servo Drives

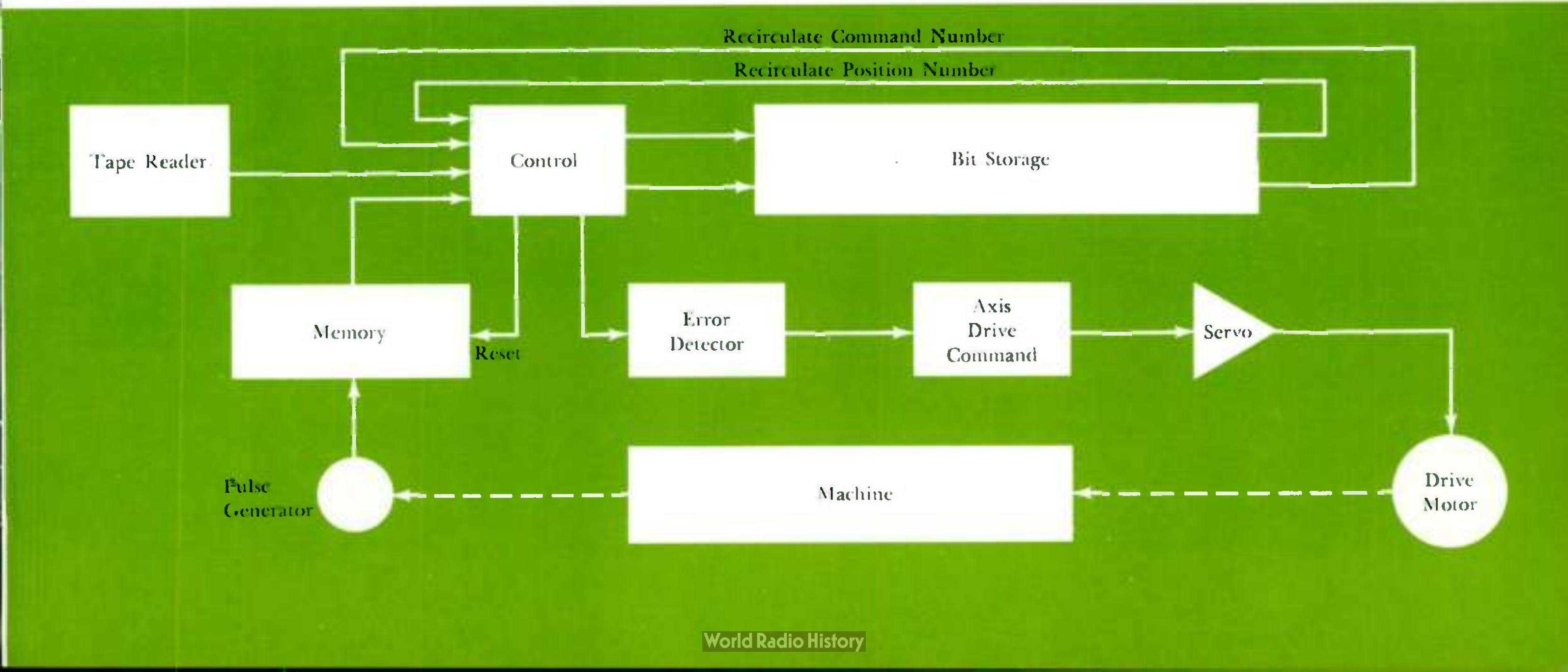
Two types of drive are available for feed and positioning service. The one recommended for larger machines requiring considerable torque capability is a solid-state dc servo supplied in ratings up to one horsepower. It consists of a dc shunt motor and a thyristor control that regulates the motor armature power. Operation of the thyristor firing circuit is practically instantaneous, making for fast response.

For smaller machines, a dual-motor drive is available. It consists of a stepping motor and an ac squirrel-cage traverse motor, in ratings up to one-fourth horsepower of the traverse motor and in 135 to 200 inch-ounce capabilities of the stepping motor. The ac motor is used for traversing, and the stepping motor produces the medium and fine positioning speeds at pulse rates controlled by power transistors.

Conclusion

The design of an integrated-circuit numerical control and its successful application to a machine tool establish a sound basis for applying the new control to other machines within its capabilities. It also serves as a stepping-stone to numerical control systems of greater capability and to other industrial control applications of integrated circuits.

Westinghouse ENGINEER
September 1965



3—Simplified block diagram of the positioning control system for one axis of motion control. It is a serial digital system, which permits extensive time-sharing of circuit components and thereby further reduces the number of components required.

Design Features of the San Onofre Nuclear Station

by H. J. von Hollen
C. F. Currey

Several new design concepts have been incorporated in this nuclear plant, the net result being significant improvements in simplification and overall performance.

Nuclear power plants are at a development stage where each successive design can incorporate not only design refinements learned from experience with previous plants, but also more major changes resulting from continuing development effort. Such is the case with the reactor plant for the San Onofre Nuclear Generating Station now under construction on the Southern California coast. For example, the major reactor components will be the largest yet built for any pressurized water reactor, in some cases double the size of previous units; and the reactor will be the first to use a new control-rod concept, called Rod-Cluster Control, in a large power reactor.

Plant Description

The San Onofre Nuclear Generating Station, situated just south of the city of San Clemente, will be a major generating plant addition to the Southern California Edison and the San Diego Gas and Electric Systems. The plant will be operated by Edison, with 80 percent of the net output being delivered to Edison and the remaining 20 percent to San Diego.

The general arrangement of the plant is shown in the vertical section view, Fig. 1. The pressurized water reactor coolant system will be located inside the 140-foot-diameter containment sphere, which is constructed of one-inch-thick steel. Three parallel heat-transfer loops are connected to the reactor vessel, each with its own steam generator and coolant circulating pump.

The turbine generator is an 1800-rpm tandem-compound impulse reaction unit, with a dual-flow high-pressure turbine and quadruple-flow low-pressure ends having 40-inch-long exhaust-row blading. The generator is a hydrogen inner-cooled machine rated at 500 mva, 90-percent power factor. Plant output is 450 mw gross.

Construction for this new plant began at the site in July 1964. Precritical testing is scheduled for early 1966 and fuel loading during the latter part of that year. The engineer-constructor for the station is the Bechtel Corporation, with Westinghouse serving as the designer and manufacturer of the nuclear steam supply system and most of the major secondary plant equipment.

A photograph of construction progress at the site as of July 1 is shown at right. The containment sphere, which houses the reactor primary system, is essentially complete and dominates the photo. To the left front of the containment is the control and administration building. The turbine generator pedestal extends to the left. The huge gantry crane, which is used both during plant erection and to service turbine generator equipment, can be seen at the left end of the pedestal, on which it has full lengthwise travel.

A major benchmark in the construction program was achieved in May when the 325-ton reactor vessel was delivered to the site. The trip from Chattanooga by rail, barge, and steamship transportation, was climaxed by a 17-mile overland haul on a special 128-tired trailer. The reactor vessel can be seen at the right rear of the containment beside the roadway.

Nuclear Plant Systems

Reactor Coolant System—The major components in the connected loops of the primary system will be the largest built to date for any PWR plant. For example, each steam generator has 27,700 square feet of effective heat-transfer area, almost double that of the Yankee-Rowe and Selni units. The pumps have roughly two and one-half times the flow capability of pumps previously used. The use of such large equipment not only reduces the number of components but also simplifies the associated complexities of layout, controls, and auxiliary systems, resulting in a more economical and operable plant.

To improve turbine cycle efficiency, secondary plant steam pressure has been increased, necessitating consequent increases in reactor coolant system operating temperatures. The reactor system, designed for 2500 psia, is maintained at a normal operating pressure of 2065 psia by an electrically heated pressurizer. At a 450 mw(e) power level, 210,000 gpm of coolant enters the vessel at 553 degrees F and exits at 597 degrees F. The 420-degree-F feedwater is heated to produce 5,700,000 pounds per hour of dry and saturated steam at 710 psia, 505 degrees F for the secondary plant. The net plant efficiency attained is almost 32 percent, approximately 4 percent higher than Yankee-Rowe.

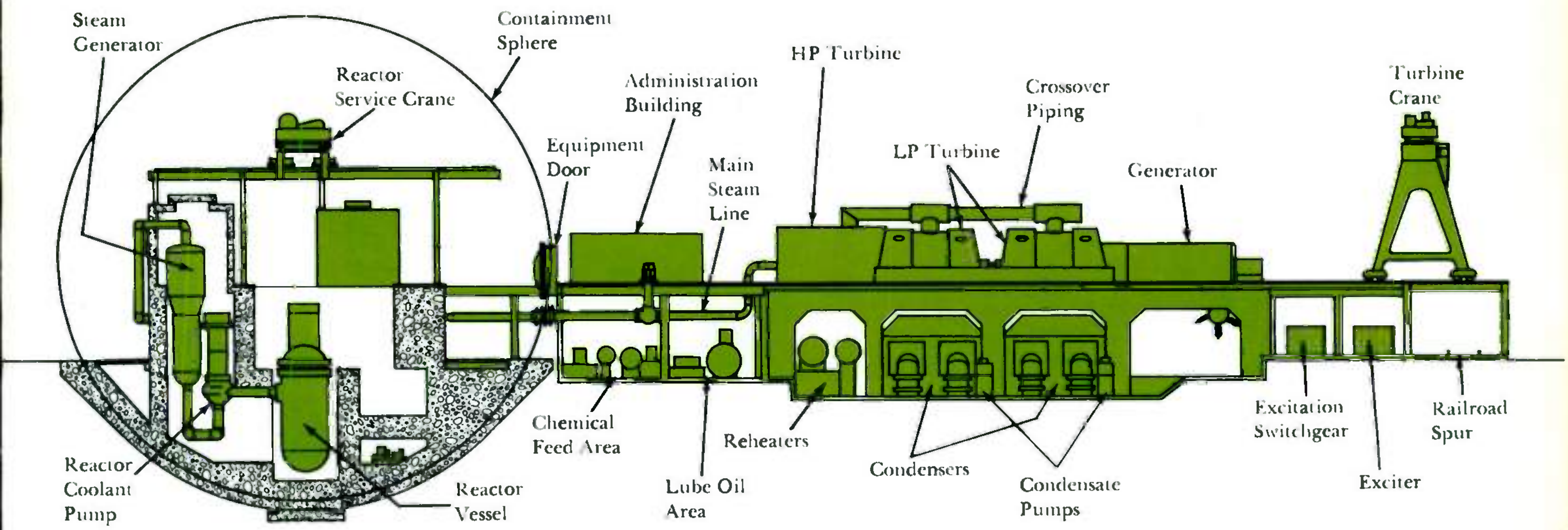
Loop isolation valves have been omitted in the San Onofre plant design because of the confidence generated by past operating experience. Check valves that were previously furnished in each pump suction line to prevent backflow and reverse pump rotation are no longer required because of the design selected for the pumps.

Reactor Core—This is the first large power reactor to employ an advanced reactor control-rod concept called Rod-Cluster Control (RCC). In this approach, a series of small individual control elements arranged in a cluster (see Fig. 2) replaces the previous cruciform control rod.

The core contains 157 fuel assemblies, each fuel assembly having 180 fuel tubes arranged in a 14-by-14 square lattice. In this lattice, 16 spaces are provided with stainless steel thimbles designed to accept the RCC control elements; these elements consist of 0.430-inch-diameter stainless steel tubes

1—General arrangement of the plant is shown in the vertical section above right. Construction photo at right was taken on July 1.

H. J. von Hollen is Manager of the San Onofre Project, and C. F. Currey is the Project Engineer. Both are members of the Atomic Power Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.


Steam Generator
Containment Sphere
Reactor Service Crane
HP Turbine
Administration Building
Crossover Piping
Turbine Crane
Equipment Door
Main Steam Line
LP Turbine
Generator
Chemical Feed Area
Reheaters
Condensers
Condensate Pumps
Excitation Switchgear
Railroad Spur
Exciter
Reactor Coolant Pump
Reactor Vessel
Lube Oil Area

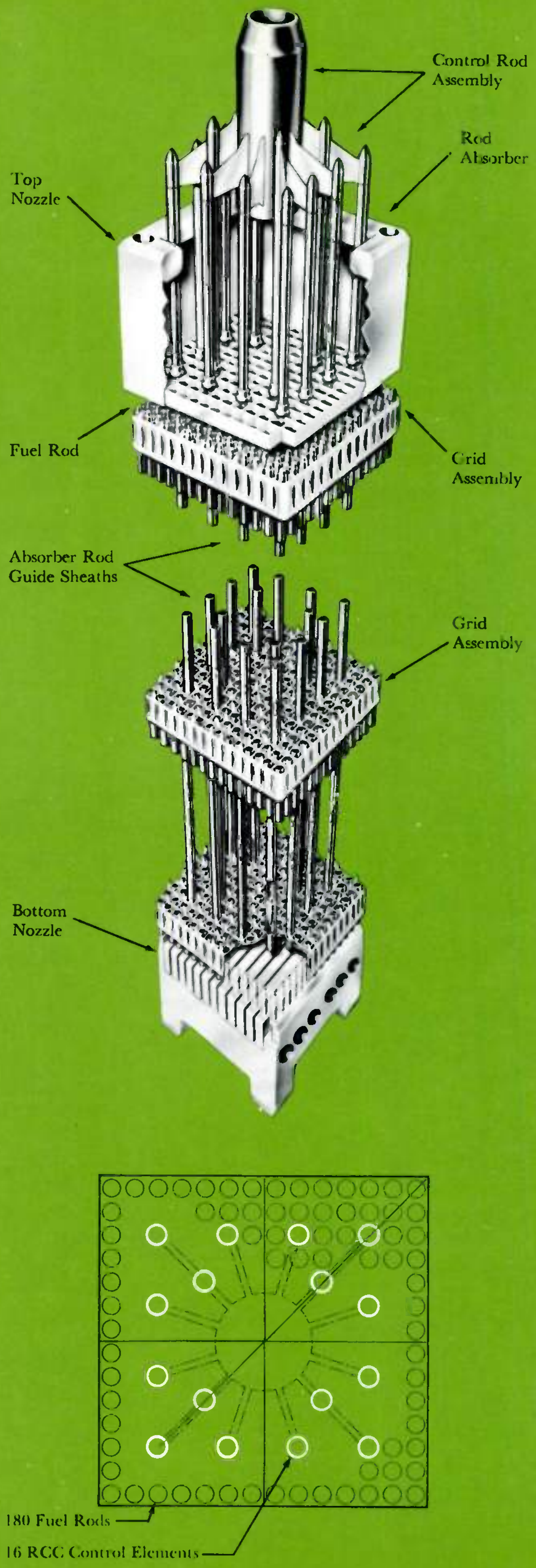
containing silver indium cadmium rods. RCC elements are located in 45 of the 157 fuel-assembly positions, uniformly distributed about the core. Each group of 16 control elements in the controlled assemblies makes up one control rod, which is connected to a control-rod drive mechanism mounted on the reactor-vessel head.

The introduction of RCC control has permitted several worthwhile improvements that have simplified the plant and have improved plant performance. Since these control elements are more uniformly dispersed throughout the fuel assemblies, control-rod followers are not needed. This has permitted the reactor vessel to be shortened by nearly six feet, with a consequent reduction in reactor coolant volume. The containment design is a direct function of the reactor coolant-system volume. Since the containment was originally sized for the reactor system employing cruciform-type control rods, adoption of the RCC concept for this plant has made possible a reduction of the containment design pressure.

The core contains about 150,000 pounds of nuclear fuel in the form of sintered uranium-oxide pellets, 0.380 inch in diameter, of an average 3.5 percent initial enrichment. The pellets are sealed into 125-inch-long stainless steel fuel tubes. A three-region, three-cycle fuel management program is utilized in combination with the chemical-shim control concept to achieve a relatively flat power distribution. At the first refueling, the central-region fuel assemblies are removed and the intermediate-region assemblies are "cycled" into the open central locations. The outside-region assemblies move into the empty intermediate locations and are replaced in turn by new fuel assemblies of 3.8 percent feed enrichment. This procedure is repeated at each refueling. For the equilibrium core, the plant will operate at 450 mw(e) with approximately 14 months between refuelings.

Reactor Coolant Pumps—All previous large PWR plants for station service (Yankee, Selni, Indian Point) have used Westinghouse canned motor pump units because the hermetically sealed construction prevents any possibility of leakage of radioactive coolant and also because they are especially suitable for operation in high-pressure (1500 to 2000 psia) reactor coolant systems. These pumps have proven to be extremely reliable and have relatively simple auxiliary system requirements. Canned motor pump units do, however, have special motor designs requiring a long production time and have evaluated electrical efficiencies about eight percent below that of pumps powered by conventional motors.

An additional worthwhile advantage of conventional pump construction is that mechanical inertia in the form of a flywheel can readily be incorporated into the motor design. This inertia is helpful in meeting the requirement to maintain some reactor coolant pump flow for about 10 seconds follow-



2—**RCC element** as it fits into fuel assembly is shown above right. Vertical view at right shows position of the 16 control elements in the fuel assembly.

ing scram to prevent a sudden reduction of effective cooling, which could result in possible fuel cladding damage due to over-temperature. This requirement results from the continued heat production by the reactor core following a scram, due to the release of sensible heat from the fuel to the coolant, and from residual heat generation from the decay of fission products. With an average fuel temperature of 1625 degrees F, the heat release from the fuel is equivalent to 8 to 10 seconds of reactor full-power operation.

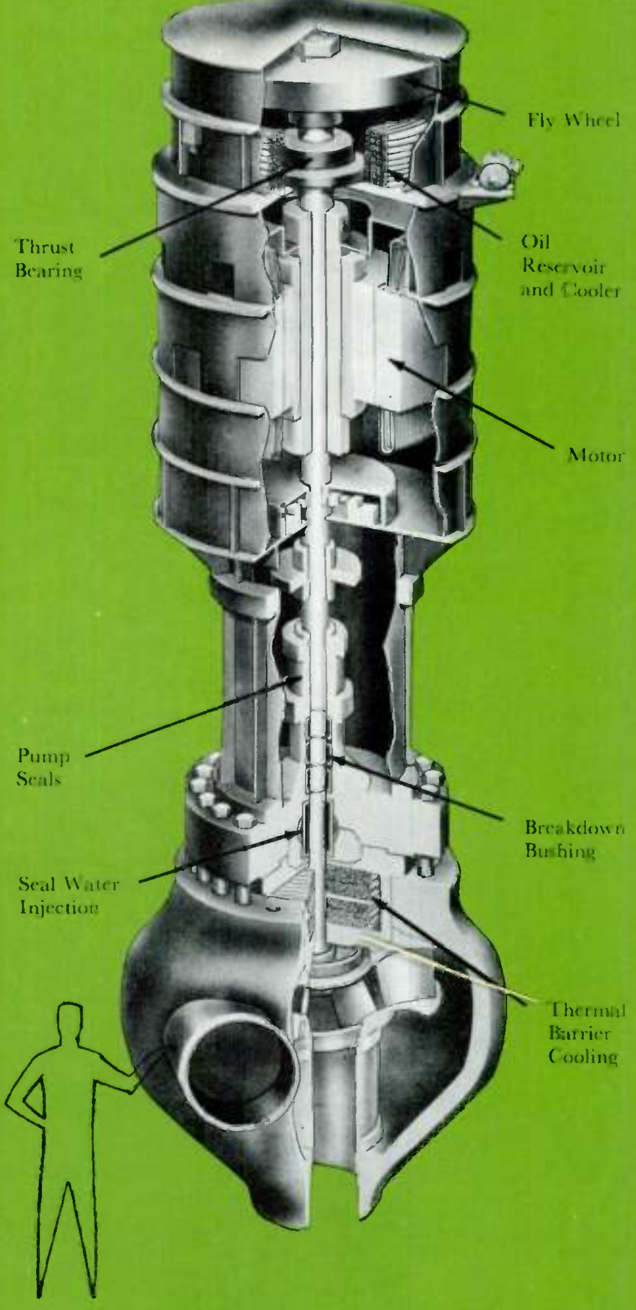
A comparison of the flow coastdown for a controlled-leakage pump having the desired flow coastdown characteristic with a canned pump is plotted versus time in Fig. 3. Residual heat generation and average core heat flux are also plotted to give a rough indication of the requirement to maintain flow after scram. For instance, a "loss of flow" reactor trip will drop the control rods and effectively shut down the nuclear reaction in 2.3 seconds. However, the core heat flux will continue at a significant fraction of its original value due to a 7- to 8-second thermal time delay for release of heat from the fuel into the coolant. This is due to the relatively low thermal conductivity of the fuel.

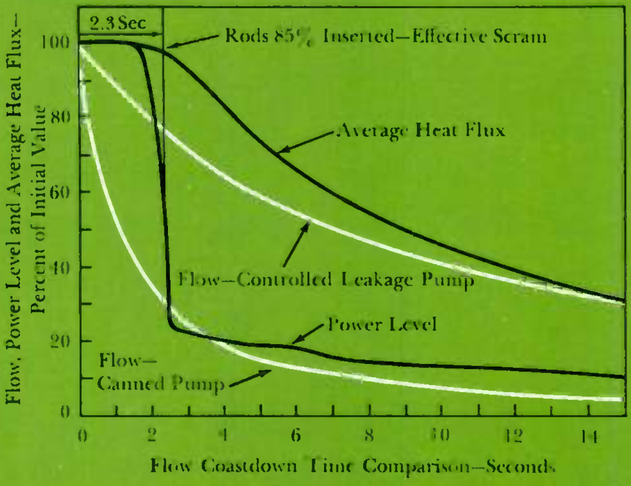
Considering these factors, particularly the potential for reduction in auxiliary power consumption for the large size of pump required, a pump-motor unit of conventional design was chosen. The unit selected is shown in Fig. 3. It is rated 70,000 gpm at 200 feet head and is driven by a vertical, 4000-horsepower, 4160-volt induction motor. The inertia of the rotating assembly is selected to provide sufficient flow coast down to protect the core if all pumps are tripped simultaneously at full reactor power.

The pump shaft seal arrangement is especially developed for reactor service, with a primary and two backup seals. Seal injection water is obtained from the high-pressure reactor-charging pumps, which are basically part of the reactor auxiliary equipment to provide reactor coolant makeup. The primary seal has a nominal two-gpm leakage, which is collected by the backup seals and is returned to the reactor coolant system.

Safety Injection System—Although the possibility of a rupture in the reactor coolant system is extremely remote, provisions have been made in the plant to minimize damage to equipment and to provide for public protection against a "loss of reactor coolant" accident. A safety injection system, consisting fundamentally of a high-flow, high-pressure pumping system, is provided to inject large volumes of borated water into the reactor vessel, protecting the reactor core from excessively high temperatures that would soon result from the loss of cooling.

Operation of the safety injection system is initiated automatically by coincident signals of low level and low pressure in





3—Flow coastdown characteristics of controlled leakage pump and canned pump are shown at right. An artist's rendition of the controlled leakage pump is shown at top right.

the reactor coolant system. Two high-flow, low-head safety injection pumps deliver borated water into the suction of the feedwater pumps, which discharge directly into the reactor system for this service.

Plant Instrumentation and Control

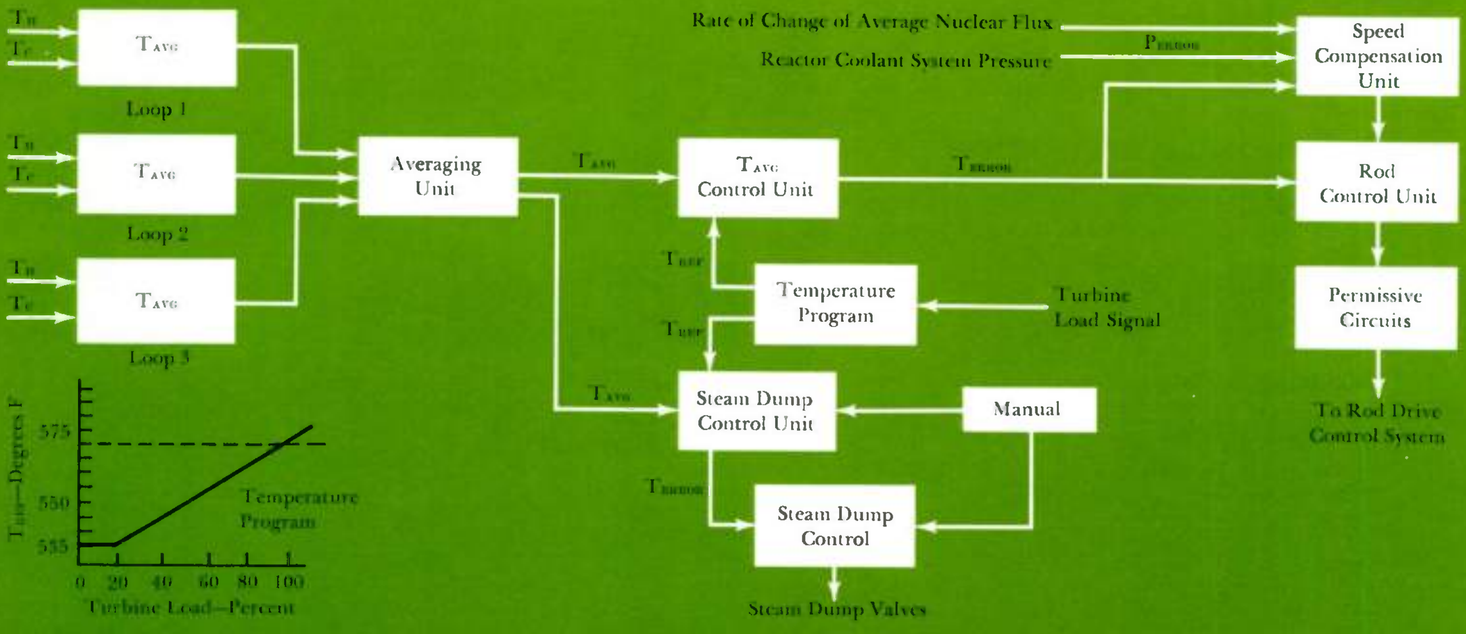
The guiding philosophy used in the design of the overall plant instrumentation and control systems has been modeled after that used in the most recent Southern California Edison and San Diego Gas and Electric fossil-fueled stations. The plant employs the "Centralized Control" concept in which control of all the major plant equipment and systems is brought together and integrated in one control room. The arrangement of the controls is such as to permit a single operator at the control console to operate and control the entire plant while delivering power to the utility networks.

Above the 20-percent power level, both the reactor and the turbine generator are automatically controlled, with loading supervised by the operators as dictated by the power demand communicated from the utility-system dispatchers. Long-term reactor control is achieved by employing chemical shim—adjusting the concentration of boric acid, a neutron absorber, as required to compensate for reactor fuel burnup and the reactivity required to take the plant from ambient to hot operating conditions. Short-term control of the reactor for plant loading, maneuvering, and to provide emergency shutdown capability is furnished by the mechanical control rods.

Advantage has been taken of the pressurized water reactor's inherent capability to accommodate utility-system load transients. At full load, the plant has the capability to accept, without tripping, utility load changes of a ±3-percent ramp, ±10-percent steps, and a 30-percent load drop.

As is customary in conventional stations, to avoid unnecessary station trips, the protective circuits associated with the turbine plant are arranged to "energize to trip." For the reactor, however, the accepted nuclear industry practice of "de-energize to trip" circuitry is employed. Recognizing that this arrangement increases the sensitivity to conditions that might cause spurious plant trips, instrument channels associated with reactor protection have been strengthened by employing two-out-of-three and two-out-of-four coincidence circuitry. These are arranged so that coincident trip signals from at least two channels are required to initiate a reactor trip. This has the advantage that erroneous signals from a single channel will not trip the plant but will be alarmed, and that the failure of any channel to trip when required will not compromise plant safety. This arrangement also enables one complete channel to be taken out of service for maintenance,

4—Reactor control system, shown here in simplified form, controls power level from 20 percent to full power.



with the remaining channels temporarily operating on a one-out-of-two basis.

Reactor Control System—Since San Onofre is an integral part of the interconnected Edison-San Diego electrical system, the plant must respond to the frequency and power requirements of these systems. A standard Westinghouse speed sensing turbine governor provides this basic control.

The reactor control system shown in simplified form in Fig. 4 is designed to provide dependable automatic control of reactor power level in the range from 20 percent to full power. Reactor coolant average temperature and turbine load are the system variables measured in order to control the position of the control rods for changes in power level. A secondary control mode extends the effective range of the control rods, by varying the concentration of a soluble neutron absorber, boric acid, in the reactor coolant.

An essentially constant reactor coolant average temperature is maintained during steady-state operation at full power. Following a scheduled or transient change in load, the control system maintains the coolant temperature on a prescribed temperature program, which is a function of turbine load, as shown in the inset in the lower left corner of Fig. 4.

Because of the inherent thermal time delays between the reactor coolant systems and the secondary plant, the reactor control system includes anticipatory signals from the rate of change of nuclear flux and from changes in reactor coolant system pressure, since these parameters respond quickly to turbine load and system changes requiring control-rod motion. A more accurate and smoother control of coolant temperature is thereby obtained.

The control system is also arranged to initiate steam dump for load reductions in excess of 10 percent. This allows immediate removal of the reactor coolant system heat while the reactor control system attempts to reduce the reactor power level to coincide with the turbine demand.

Control signals to the rod drive control system are transmitted through a number of "permissive" interlocks. These interlocks, for example, prevent rod withdrawal under certain conditions such as excessive reactor start-up rate or reactor overpower.

Reactor Protection System—The reactor protection system includes provisions for preventing abnormal operating conditions as well as protecting the reactor plant from their possible consequences. This system responds to signals from the plant process and nuclear instrumentation.

To achieve reliable plant operation, reactor trip signals are kept to a minimum consistent with overall plant safety. Protection is provided against possible core damage resulting from excessive reactor power level, detrimental changes in the reactor coolant flow, pressure and temperature, or high reactor start-up rate. Conditions such as initiation of safety injection, turbine trip, and loss of feedwater also initiate reactor trip.

Nuclear Instrumentation—The nuclear instrumentation system is generally similar to that which has been employed for other power reactors. It is divided into two groups, the first being *start-up* instrumentation, composed of source range and intermediate range channels, and the second being *power range* instrumentation used during power operation.

The overall plant capability is directly related to the degree of accuracy attainable in the reactor overpower trip settings. Thus, a prime design objective of the power range instrumentation has been to obtain more accurate monitoring of actual reactor power level. To minimize the effects of local core flux perturbations due, for example, to control-rod motion, each power range channel receives an averaged signal from two power range detectors in a common axial thimble located at approximately ¼ and ¾ core height respectively. A total of four power range channels are furnished, each utilizing two power range detectors located in four instrumentation thimbles arranged axially around the periphery of the reactor vessel at 90-degree intervals.

Rod Control System—The 45 control rods are divided into three "groups" consisting of two shutdown groups of 8 rods each and one control group of 29 rods. The control group is further split into two banks of 17 and 12 rods, respectively, which operate in a sequential manner.

The rods are held in position and moved as required in ⅜-inch steps by sequenced operation of the three 125-volt dc coils on each mechanism. Each group "cycler," employing a set of slave motor driven cam switches, feeds signals to contactors that sequentially energize the mechanism coils.

The two groups of shutdown rods are maintained in the fully withdrawn position and together with the control group have sufficient reactivity worth to shut down the reactor from full power to hot standby with any one rod stuck. The shutdown groups are manually controlled and are moved at a constant speed of 15 inches per minute.

Movement of the control group may be either manual or automatic; the automatic signal from the reactor control system is used to vary control-rod speed as required.

Conclusion

In summary, the San Onofre design incorporates not only detail refinements from previous designs, but also major developments such as Rod Cluster Control. The utilization of these developments for San Onofre represents the initial application in a new generation of large reactor plants, and leads the way to still further developments.

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September 1965

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Computer Simulation of A Steel-Mill Ingot-Processing Area

by Dr. E. Y. Kung
Dr. K. Chen
P. B. Skov

Plant simulation on a digital computer is being used to test new decision rules aimed at increasing production from present facilities. It also tests the effect of new production facilities on total plant production capacity.

Automatic control at the level of single variables has reached a relatively mature state. More recently, with the availability of effective computer control, automation has been carried to the level of processes with multiple variables. This capability is far enough along to consider the integration and automation of several processes of a steel plant on a scientific basis.

A plant using current steelmaking methods probably never will be completely automated because of the complicated product mix and the sheer economics of maintenance and material handling. On the other hand, these very factors suggest that operation scheduling and production control are areas in which human operators can get effective help from computers and their related equipment. It would be expensive and impractical, however, to test different production control schemes and scheduling decision rules on a real plant. Moreover, it is desirable to determine the relative costs of adding control equipment or expanding production equipment to increase production capacity. Therefore, the logical first step toward integrated automation of a steel plant is simulation of the plant. With a simulation, imaginative control schemes can be tested cheaply, quickly, and safely, and various expansion plans can be assessed on a scientific basis.

Most of the published work on steel-plant scheduling and production control has been done in Great Britain. Computer simulation has been used there to study a stripper-yard and soaking-pit operation[1] and a melting-shop operation[2]. The advantage of dynamic planning of production (controlling the composition of a heat at the end of steelmaking in consideration of the load pattern in the soaking pits) has been investigated[3]. Computers for production planning and work progress checks will implement an improved scheduling system for hot-strip rolling, annealing, and temper rolling[4,5]. In the United States, computer simulation has been used in determining production requirements of soaking pits[6].

The simulation of the ingot-processing area of the Aliquippa works of the Jones & Laughlin Steel Corporation, described in this article, goes beyond previous simulation work in at least two respects: the simulation includes all processes that have strong interactions, and it has been validated by comparing computer results with actual plant performance.

The ingot-processing area was chosen for simulation because the study was motivated by the question of soaking-pit capacity (i.e., whether or not the pits were a production bottleneck and, if so, how operations could be modified to eliminate or alleviate the bottleneck). The area is diagrammed in Fig. 1. A heat of steel from any of the steel-making furnaces is tapped into a ladle. The ladle of steel is transported by a crane to a pouring platform and poured into ingot molds waiting there on a "drag" of railroad cars. The drag of molds is held for a time specified by the metallurgical department, and then it is brought to the stripper yard where the molds are stripped from the ingots by cranes. The ingots continue to the soaking pits and are charged into the pits. After the ingots are heated to a uniform temperature, they are taken to the blooming mill, where they are rolled into slabs or blooms. The slabs are moved out a side door to the slab yard, to be reheated later and rolled in the hot strip mill. Blooms destined for a seamless tube mill also move out the side door to a storage yard, while other blooms are rolled immediately in the billet or bar mill.

Three factors complicate the scheduling and controlling of production: uncertainties, nonuniformities, and dependence of heating time on track time.

Ingot-processing area *(left)* at Jones & Laughlin Steel Corporation's Aliquippa Works centers around the soaking pits. A crane at right removes a heated ingot from a pit while other ingots (foreground) wait on a "drag" of railroad cars to be charged into the pits. The ingot buggy at left is carrying a heated ingot to the blooming mill.

1—Plant diagram *(right)* illustrates how material flows from the steel furnaces to the rolling mills. The ingot-processing area was simulated on a digital computer so that it could be "operated" under various conditions to economically test the effects of changed procedures, changed facilities, or both on plant production.

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Uncertainties occur because processing times in the steelmaking furnaces cannot be predicted accurately and also because chemical analysis of a heat may show it to be unusable for its intended purpose. Moreover, equipment breaks down frequently because of heavy use, and the breakdowns are unpredictable in time, location, and duration.

The problem of nonuniformity stems from the different types and sizes of production facilities and the variety of semifinished products that have to be produced, the latter calling for ingots of different size, type, mold practice, and steel grade. These different process and product characteristics govern the processing times and the routing of the ingots.

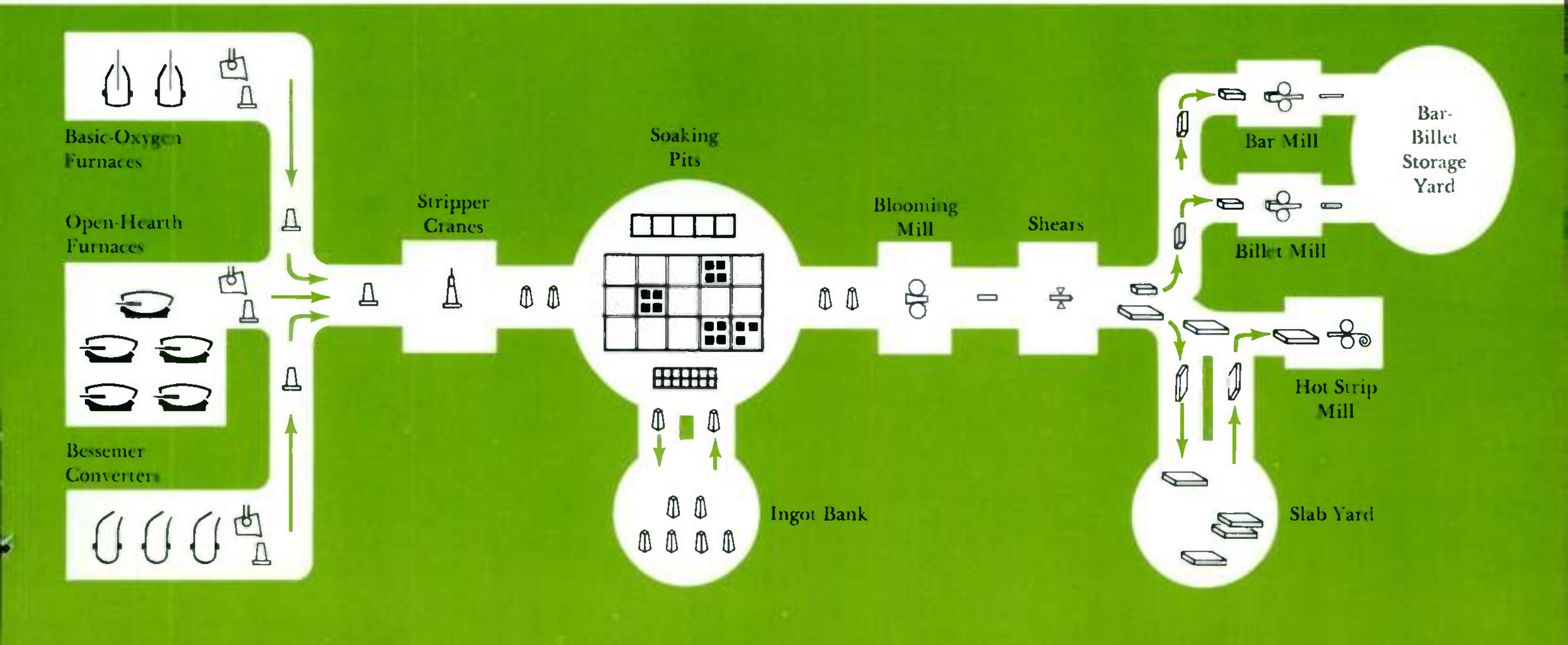
These nonuniformities and uncertainties, especially the uncertain furnace processing times and the random occurrence of equipment breakdown, are manifested in delays. Soaking pits may not be available when a heat of ingots is ready for charging, causing the ingots to wait and accumulate excess track time. Since heating time for ingots increases with their track time, this difficulty can be self-aggravating—the longer heating time required by the delayed ingots increases the probability that no empty pits will be available to receive later ingots. Another delay is the no-hot-metal delay, which occurs when the blooming mill is waiting for ingots and none are ready to roll. In contrast, at other times too many ingots are ready to roll, prolonging occupancy of the pits and decreasing throughput.

The common method for easing scheduling problems caused by nonuniformity and uncertainty is to provide more operational units than would be needed if these problems did not exist. To illustrate, the production rate of the Jones & Laughlin plant at 100-percent operating level is approximately 7000 tons per day. Since the average required heating time is around 3½ hours, the holding capacity required for the pits would be less than 1020 tons if all ingots could be drawn from the soaking pits as soon as they were ready to roll and if all pits could be recharged as soon as they became empty. However, the actual holding capacity of the plant's pits is approximately 1900 tons because, of course, in actual operation it is impossible to draw all ready-to-roll ingots immediately and to recharge all empty pits promptly. Also, a number of pits are usually in need of repair at any one time. Nonetheless, the discrepancy between the number of pits theoretically needed and the number actually provided illustrates the point that accurate prediction of plant capacity justifies careful study, even though nonuniformity and uncertainty make the prediction difficult. Solving the problem by adding capital equipment such as soaking pits and cranes is such an expensive approach that optimum control or scheduling schemes—and hardware to implement them—are well worth developing.

The Simulation

The simulation consists of a set of logical statements, expressed in the form of a computer program, that describes the routing and sequencing of heats through the ingot-processing area. In addition to the program, two types of data must be supplied to the computer: a description of the arrival times and characteristics of heats that enter the area, and the numerical values of all parameters used in the program to describe process times and equipment breakdown statistics.

The Monte Carlo technique is used to handle the problem of uncertainty. That is, plant characteristics that vary randomly, such as process times and breakdown duration, are described in a statistical manner only; the actual characteristics at any given time are determined by random sampling



from distributions determined by the statistics. Thus, the simulation is much like a pilot plant. Each computer run represents one statistically feasible plant operation for the specified length of time and the given initial conditions. To determine the average or expected plant performance, several runs are made and the performance indices averaged.

Building the Logical Model—The study was motivated by the question of soaking-pit capacity, but the throughput of the pits is intimately related to both upstream and downstream operations. Therefore, the simulation was extended on the upstream side to the pouring platforms, since heating time in the pits depends heavily on the track time of the ingot (time between pouring and its charging into a pit). On the downstream side, the simulation was extended to the first inventory accumulation areas, which keep soaking-pit operations relatively independent of subsequent processing steps (Fig. 1).

Simulating every plant detail would require excessive computer memory space and execution time, and insignificant details would obscure the significant issues. Therefore, simplifications were made.

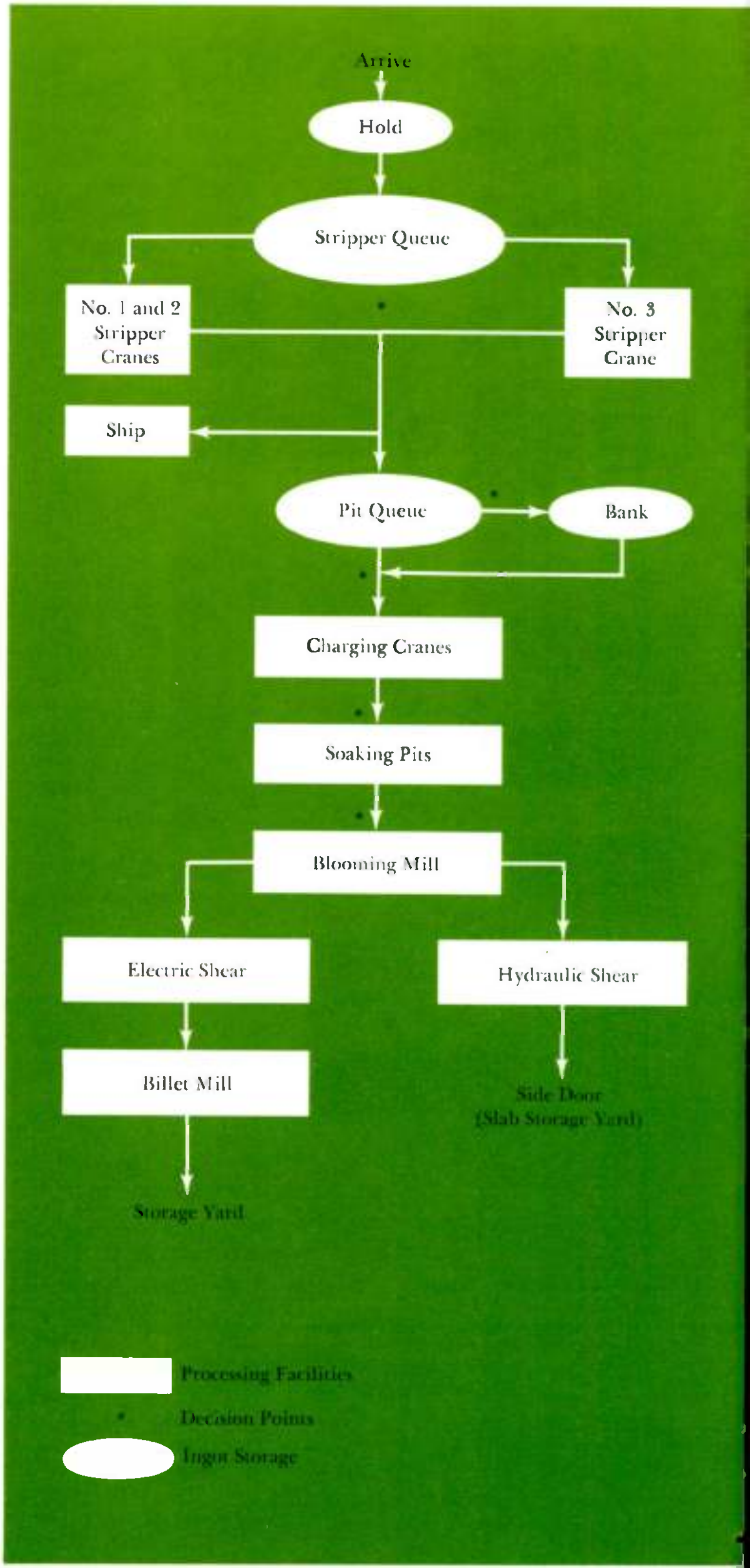
To simplify the material flow scheme, some operations that appeared to have only a small effect on plant performance were neglected and others were combined. For example, the bar mill was omitted because it handles only about 5 percent of the product; blooms normally handled by the bar mill were assumed to be routed to the billet mill (Fig. 2).

For process times, it was assumed that each processing facility, with the exception of the soaking pits, requires a fixed time to process a given heat. Heating time in the pits was calculated by equations developed by Jones & Laughlin.

Pit breakdowns were simplified by assuming that one of the large pits was down at all times of high production level, as was the case in May 1963. For the rest of the facilities, breakdowns were assumed to occur at the completion of the processing of each heat with a probability proportional to some characteristic of the heat. The proportionality factor was chosen so that the average number of breakdowns agreed with data compiled from plant records. Duration of breakdown was given as a function of x, which is uniformly distributed bebetween 0 and 1 and also matches mill data.

A further simplification was made by using the heat as the standard unit of material throughout the simulation. This unit is large enough to avoid unnecessary detail and is also actually used in the plant. Heats were identified by furnace type, ingot size, number of ingots, product type, blooming time per ingot, and metallurgical hold time.

Rules were then formulated for routing and sequencing heats and for allocating equipment. Since the first task in the simulation was to establish its validity by comparing computer results with actual operating records, the decision rules used in



2—Material flow was simplified for the computer simulation by combining some operations and omitting operations that had little effect on plant performance. This diagram is the basis of the logical model of the ingot-processing area.

the plant were used in the simulation. Now, however, in applying the simulation to test alternate production control schemes and scheduling policies, decision rules corresponding to the new schemes and policies are being used. Actually, in present plant operation no rigid decision rules are used all the time, and human judgment is frequently involved. The rules formulated for the simulation therefore are interpretations of practices used with reasonable consistency in the plant. As shown in Fig. 2, decision rules have been applied in five places: stripping, banking, charging, pit allocation, and blooming.

In *stripping*, track congestion problems are considered, and the No. 3 crane gives priority to large ingots because it is the only one able to strip them. Stripping is stopped if there is too much steel in the pit queue, to avoid congestion in the charging area. Heats of ingots are *banked* if heavy congestion develops on the track or if they become cold before they can be charged into the soaking pits. Heats are *charged* from the pit queue on a first-come first-served basis. They are charged from the bank if the pit queue is empty and sufficient pit space is available to accommodate all hot steel expected in the next two hours. Soaking pits are *allocated* to heats according to one of two tables of priorities. One is for light charging (charging less than the full load), which is normally in effect. The other is for heavy or full-load charging. Drawing ingots for rolling in the *blooming* mill is on a first-ready first-served basis, with the constraint that a proper exit path must be available. Also, since the billet mill rolls more slowly than the blooming mill, the rolling of a heat of billet product is interspersed with a few ingots for the side door to allow full use of the blooming mill.

In addition to these rules are the rules regulating turn length (operating duration) for the blooming mill. Turns are ended when there is enough pit space to accommodate all hot steel expected before the start of the next turn and when the number of ingots in the bank is small. In addition, the mill is down for an entire turn once a week for maintenance.

Next, the actual logical model was formulated. This model consists of logical interactions and sequences of events, which occur at discrete times when the position, quantity, or status of the material, or the status of the processing equipment, changes. Examples of events are "begin charge," "finish crane repair," and "finish pour."

Table 1—Outputs of the Computer Simulation

Report on Occurrence
a. Breakdown (time, duration, and type of facility).
b. Charging from bank (time and product type).
c. Blooming mill idling (time, duration, and cause).

Report Hourly
a. Number and size of ingots expected from the steelmaking shop in the next 2½ hours, in stripper queue, in pit queue, in bank, being heated in soaking pits, and ready to roll.
b. Number and type of empty pits.

Report Daily
a. Total rolling delays.
b. Gross operating hours.
c. Average track time.

Some events occur exogenously; that is, without regard to the condition of the operation under study. Others occur endogenously; that is, they are caused by the internal workings of the operation. A "finish pour" is exogenous since the pouring operation is outside the simulated area and so is not affected by operations in the simulated area. A "begin charge" is endogenous since its timing depends on the internal workings of the simulated operation. For example, the event "finish move" (of a heat to the charge queue) may signal the scheduling of the event "begin charge," or the scheduling may be delayed to await the event "finish crane repair."

Data Collection and Reduction—To get quantitive results from the simulation, numerical data describing the heats that arrive at the area and the characteristics of the production equipment must be supplied to the computer.

Actual finish pour times and characteristics of heats produced during May 1962 and May 1963 were deduced from plant records. Thus, two sets of heat inputs were prepared, which duplicate actual steel production for the two months. In making runs to check the model, simulation was begun at the end of the first Sunday downturn (eight-hour shift devoted to maintenance) and carried through the end of the month. A representative initial assortment of ingots was placed in the bank and the soaking pits. The same heat inputs and initial conditions were used in all computer runs.

Data describing the characteristics of the production equipment consists of process times and breakdown statistics. Process times were obtained either from plant data or through direct observation. Breakdown statistics were obtained by assuming their statistical forms and choosing the constants in these forms so that means and variances of simulated and observed breakdown duration and spacing were in agreement.

Computer Program—The logical model and data described above composed the model of the simulated plant area. The task remained, however, to convert these into a computer program that could be used to generate outputs from the model. To simplify the programming, a simulation programming language was sought that would require substantially less programming time and fewer instructions than do conventional languages such as Fortran. Simscript[7] was chosen as the most suitable. With it, the flow diagram of the logical model was programmed almost directly. In a computer run, the Simscript package automatically determines, on the basis of initial conditions and other numerical parameters, which event is to occur first. Then the subprogram describing that event is executed, perhaps creating new or destroying old events. The package then automatically selects and executes succeeding events until the entire simulation period is completed. Information reported during a run is listed in Table 1.

Testing the Simulation

To determine whether the simulation is a valid representation of the real operation, simulation results were compared with actual plant performance for the months of May 1962 and May 1963. The comparison was made by three performance indices: rolling delays, net operating hours, and average track time. These indices are used in the plant to keep watch on the operation and therefore are items on which reliable records are kept. Comparison also was made between simulation and plant on the behavior of the cold-ingot bank. The bank normally builds up when the blooming mill is down eight hours each Sunday for maintenance and is depleted gradually during the week. However, whenever any situation develops in which a heat gets cold before it can be charged into the soaking pits, it is banked. Therefore, bank behavior measures the ability of the plant to recover from the Sunday downturn and maintain smooth operation, and it shows when the amount of steel being processed is more than the plant can handle. A final test of the simulation was made by checking the reaction of the simulation to the occurrence of events and comparing it to the response of the plant.

The behavior of the simulation indeed closely resembled that of the plant. For example, in the simulation as in the plant, a no-hot-metal delay occurred when the number of ingots ready to roll had decreased to zero. Also, ingots were charged from the bank when a large number of pits became available and the number of ingots in the stripper and pit queues was small.

The decision rules and the data on process times and equipment breakdown used in the simulation were gradually refined to improve the agreement between simulation and plant performance. The simulation results presented here were obtained from the "best" and final version of the simulation. Simulation results and actual plant data on total rolling delays, net operating hours, and average track time are compared in Table 2. For the simulation results, 2σ ranges (σ = standard deviation) were estimated from a group of 28 runs. These ranges cover the expected spans in the variation of the results due to random fluctuations at the 95-percent confidence level. For the plant data, the magnitude of the errors was estimated. The simulation results and plant data agree within or close to the 2σ range of the simulation results, the error range of the plant data, or both.

Agreement between the simulation and the plant on the behavior of the cold ingot bank was checked by comparing the number of ingots banked and charged from the bank, respectively, during each of the two months (Table 3). The numbers for the simulation and the plant are in close agreement. (Although the May 1962 figures for number of ingots banked do not seem very close, the difference is only a small fraction of the total number of ingots processed during the month.) Simulated rates of depletion between the Sunday downturns also resembled those observed in the plant. The number of ingots charged from the bank was larger than the number banked, since a considerable number of ingots were in the bank at the beginning of each period.

Table 2—Comparison of Simulation With Plant Performance

	Total Rolling Delay (hours)	*Net Operating Time (hours)*	*Average Track Time (hours)*
May 1962			
Plant	35.3 ±4.2[1]	403 ±4.2	1.77 ±0.17
Simulation	38.4 ±6.5[2]	398 ±7.4	1.81 ±0.24
May 1963			
Plant	49.2 ±5.9	551 ±5.9	1.98 ±0.17
Simulation	41.6 ±6.5	548 ±7.4	1.89 ±0.24

1. Estimated error.
2. 2σ range, where σ = standard deviation.

Table 3—Performance of Cold Ingot Bank

	Number of Ingots Banked	*Number of Ingots Charged From Bank*
May 1962		
Plant	238	432
Simulation*	143	406
May 1963		
Plant	673	903
Simulation*	675	846

*Simulation results are averages from computer runs.

Conclusion

Since the performance indices, behavior of the cold ingot bank, and response to the occurrence of events for the simulation and plant are in close agreement, the simulation is a valid representation of the plant. It is being used to estimate the capacity of the ingot-processing area for handling various product mixes and to evaluate the effect of changing the operation decision rules. Work is in progress to extend the simulation upstream and downstream to cover the entire steel plant.

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September 1965

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Integrated-Circuit Packaging Techniques

by H. G. Carter

Effective packaging techniques are required to take full advantage of the potential volume reduction in electronic circuitry made possible by the integrated circuit.

The miniaturized communication transceiver so long popularized in science fiction has become more fact than fiction. The miniature transceiver is but one example of a large variety of extremely compact devices and systems, now under development or soon to be in production, which are based on one of the most significant developments in the electronics industry—monolithic integrated circuitry.

This type of circuitry, considered interesting but experimental only a few years ago, is now a functional reality, and is demanded to some extent on most advanced military electronics systems. The extent of use is dictated only by circuit costs, power limitations, and function availability—and the situation is improving daily. Typical systems now under active development or actual construction at the Aerospace Division include a sequence generator for a deep-space ranging system, a high-altitude radar altimeter, the range control and programming unit for a command-guided homing torpedo, the pulse-ranging frequency and timer unit of an airborne radar, a video signal processor, and a large simultaneously organized parallel computer. These systems and subsystems represent the wide cross-section of applications for integrated circuitry in underseas, ground-based, airborne, and both near- and deep-space electronics equipment.

To keep abreast of this trend in circuitry, system-packaging concepts for integrated circuitry must be developed that will be standard tomorrow in the same sense that the packaging of conventional components on printed circuit boards was standard yesterday, and "cordwood" modules are standard today.

Some day, electronics systems will undoubtedly be composed of complete circuit functions formed and integrally interconnected in place on a single large active chip. But the problems associated with manufacturing yield prevent this approach from being economically feasible within the immediate future. An elementary form of this multicircuit chip approach is illustrated in Fig. 2. Five amplifiers are located on the upper chip, and four capacitors on the lower. An interim approach will probably be the arrangement of several circuit chips on a suitable substrate, interconnected by deposition or some other means, similar to the arrangement shown in Fig. 3. However, bare chips are not readily available from the circuit suppliers, nor are the interconnection approaches sufficiently developed for production use. So for systems presently being designed for production within the next few years, packaging concepts must be built around integrated circuitry in its presently available forms—a modification of the transistor TO-5 can and the so-called flat-pack.

TO-5 Cans and Flat-Packs

The TO-5 can configuration consists of the standard transistor package, but with the height reduced to 0.175 inch (Fig. 4). A wealth of technology and tooling is available for its fabrication, and the electronics industry is familiar with its performance and use. With this configuration, the output leads are on the 0.200-inch diameter circle of the standard TO-5 transistor header. Up to 12 leads have been used, and in this case, would be positioned about 0.050 inch apart.

Although the use of the TO-5 can follows a well-proven path, this device package does not take full advantage of the integrated circuit's small size—a circuit chip with a volume of 0.00002 cubic inch contained in a package with an occupied volume of 0.042 cubic inch cannot be considered good volume utilization. Attempts to improve this poor volumetric efficiency resulted in the perfection of a flat modular container, the so-called flat-pack (Fig. 4). Basically, this container is a small flat glass or metal box with ribbon output leads from its ends; the box is usually sealed with a metal lid. Since apparently no industry standard exists, there are almost as many variations of this basic design as there are device manufacturers. Case sizes used most frequently are 0.25×0.25, 0.25×0.125, 0.25×0.375 inch, with a thickness of about 0.060 inch. Five to seven leads, each approximately 0.005×0.015 inch, extend from each end of the case. While this package is far from the ultimate in volumetric efficiency, the volume of 0.0036 cubic inch does represent about an order of magnitude improvement over the modified TO-5 can. The flat-pack is a reasonable compromise between an enclosure small enough to "make the container fit the contained" and one large enough to be economically handled and interconnected.

Since these two containers are so significantly different in configuration, quite different packaging concepts are required to position and interconnect the devices into functional systems or subsystems. The TO-5 can, with its conventional round output leads, can be used in essentially the same manner as the transistor; the flat-pack, with relatively fragile rectangular output leads on 50-mil centers, must be approached with a somewhat new packaging philosophy. The TO-5 can leads are placed in such a manner that interconnecting conductors cannot easily be routed through the area of the circular pin pattern, which results in spreading of the leads and lower packaging densities; the flat-pack with leads on two sides allows greater conductor routing flexibility and tighter component spacings. If the system design allows convective or forced-air cooling, the TO-5 configuration provides an advantage; where size limitations or natural environment make conductive heat removal necessary, the large surface-to-volume ratio of the flat-pack is better.

The relative advantages and disadvantages generally attributed to these two major container configurations are

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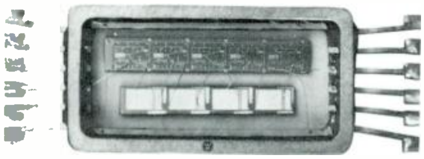
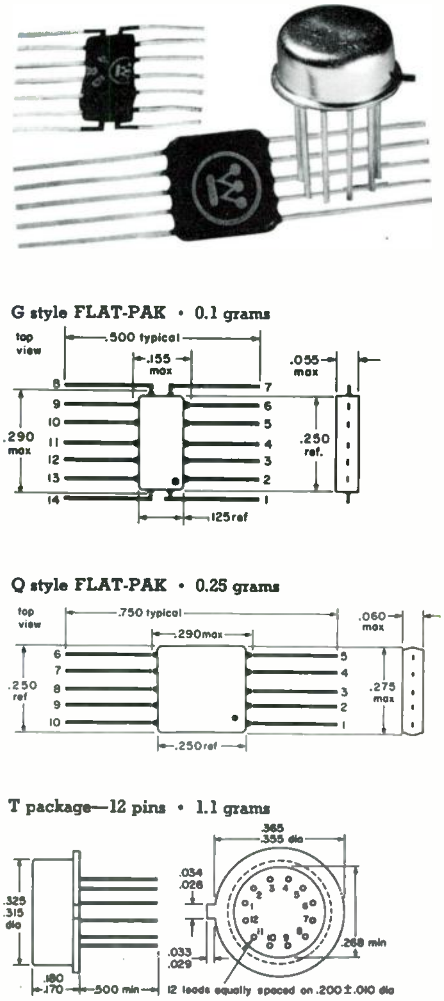
1) Single-side-band command receiver miniaturized with monolithic integrated circuitry.



2) This multicircuit chip arrangement has five amplifiers on upper chip and four capacitors on lower chip.

3) Several circuit chips are interconnected on same substrate.

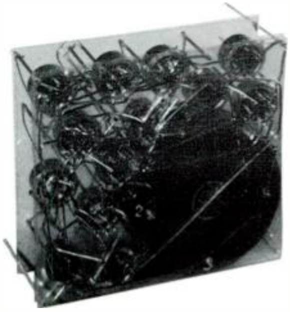


G style FLAT-PAK • 0.1 grams

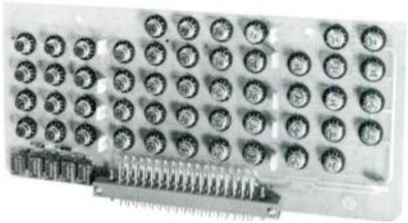
Q style FLAT-PAK • 0.25 grams

T package—12 pins • 1.1 grams

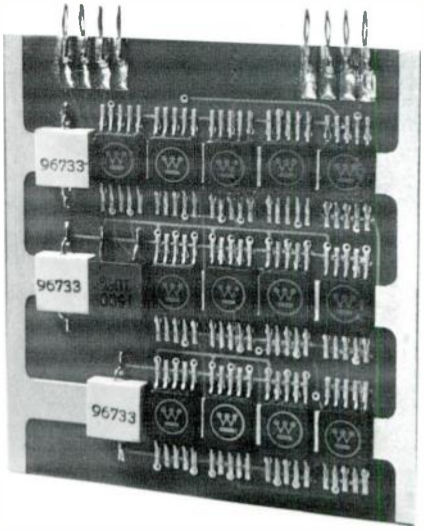
4) Mechanical characteristics of integrated-circuit containers—the TO-5 can and two versions of the flat-pack.



5) Cordwood techniques are used to minimize the volume occupied by TO-5 cans.



6) Typical arrangement of TO-5 cans on printed-circuit board.



7) Planar array of flat-packs on multilayer board.

outlined in the table below. From a packaging engineer's viewpoint, the advantages in size, weight, thermal properties, and packaging potential make the flat-pack an overwhelming choice. Many systems that do not require extremely high packaging densities, or are of a ground-support nature, can use the TO-5 can configuration. However, for space systems, high-performance aircraft, missiles, or other applications where high volumetric efficiency is of utmost importance, the flat-pack configuration is highly desirable.

Packaging Schemes

Packaging concepts that can be used to effectively capitalize on the unique characteristics of each of the two integrated-circuit container configurations are best described with illustrative examples. Although the particular schemes presented here were developed by the high-density packaging group at the Aerospace Division for specific military applications, they represent in a more general sense the existing state of the art in integrated-circuit packaging.

TO-5 Cans—Integrated circuits in TO-5 cans are most effectively fabricated into functional systems with techniques that have been proved reliable for their somewhat less complex brother, the transistor. These techniques may be grouped under two general headings—the "cordwood" submodule approach, and the standard printed-wiring-board method. For the cordwood submodule, illustrated in Fig. 5, TO-5 cans and other necessary components are stacked between two sheets of mylar film in "cordwood" fashion. Interconnections between component leads are made with rectangular nickel ribbon, and joints are formed by resistance welding. Two cans may be placed "back-to-back" between the films so that one set of leads extends from each film side; this gives the maximum packaging density since the component count can be doubled with a minimum of height increase and no increase in base-mounting area. After test, this type of package is usually encapsulated to provide both mechanical strength and environmental protection.

For the printed-circuit-board method, illustrated in Fig. 6, TO-5 cans are mounted on a standard plated through-hole printed-circuit board, either multilayer or double sided, and the leads soldered into the mounting-pad holes. Mounting a 10-lead can requires almost twice the area of the base of the can, and this does not include room for printed-circuit leads. However, since this method uses proven, well-established fabrication techniques and is relatively easy to repair, it is probably used in one form or another for most packaging systems that utilize integrated circuits in TO-5 cans.

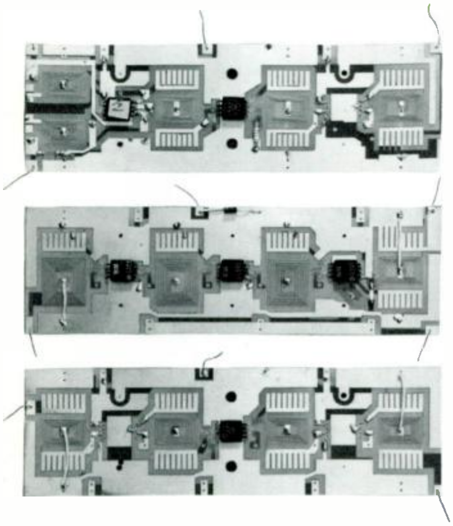
Flat-Packs—When the flat-pack form of integrated circuit is used, two basic packaging concepts are also possible—a planar array in which the units are placed on a flat surface side by side, and a stacked array with the units placed one above another. All other schemes are variations of these two basic configurations.

The geometry of the integrated circuit flat-pack makes it ideally suited to the planar-packaging approach. An assembly of this type is shown in Fig. 7. This particular unit consists of a multilayer interconnection board that has only attachment pads and a heat sink on the top surface; interconnections between pads are made on the various inner layers. The output pins are incorporated into the edge of the board to conserve height. As illustrated, the flat-packs can be placed close together and the arrangement of leads on two opposite sides of the pack provides good interconnection routing flexibility, with a potential reduction in the number of wiring layers required. The flat-pack configuration allows the placement of about 75 percent more interconnecting leads per square inch than is possible with the TO-5 can container. The rectangular shape of the output lead and its method of exit from the body of the case allow great flexibility in the method of lead attachment. The flat-pack leads may be attached to the pads on the top layer of circuitry by soldering or by some form of welding. For example, parallel gap or laser beam welding are techniques that can be used to produce a reasonably low-cost product with good repairability.

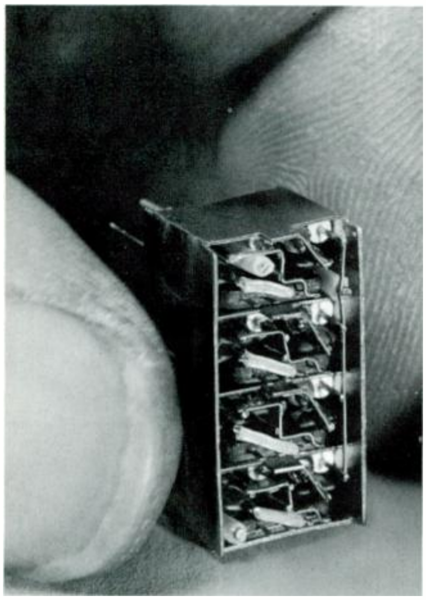
A variation on the planar technique of flat-pack packaging, a hybrid planar array, is illustrated in Fig. 8. In this package, components not obtainable in integrated circuitry (such as inductors and large capacitors) and their interconnections are formed by etching the copper-clad mounting substrate, and the flat-packs are then attached in selected locations

Comparison of TO-5 Cans and Flat-Packs for Integrated-Circuit Containers

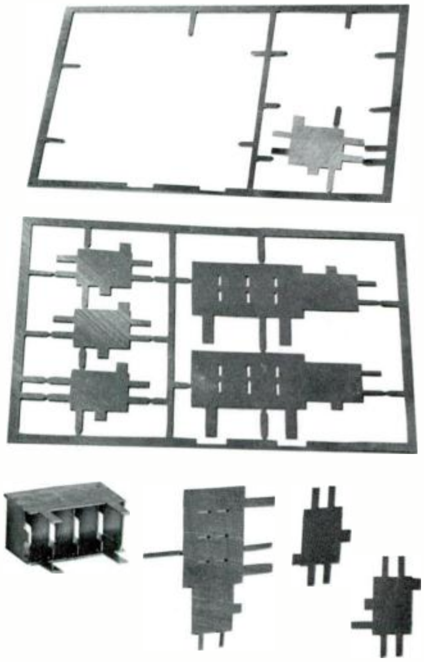
TO-5 Cans	*Flat-Packs*
Advantages	
1. Interconnection techniques well known.	1. Small size and low weight.
2. Proved through previous use in transistors.	2. Variety of lead interconnection techniques possible.
	3. High system packaging density potential.
	4. Good heat transfer by conduction.
	5. Large variety of system packaging techniques possible.
Disadvantages	
1. Poor thermal conduction.	1. Require relatively careful handling.
2. Low packaging efficiency (chip to case volume ratio).	2. Not as well proved.
3. Poor system packaging density potential.	3. Require new system packaging concepts.
4. Closed nature of pin configuration results in poor interconnection efficiency.	



8) Hybrid planar array has flat-packs mounted between etched components.

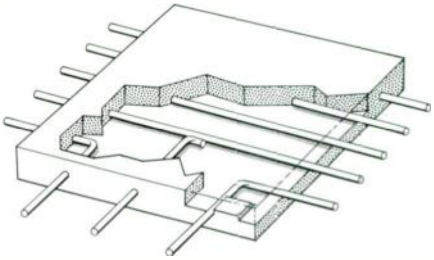


9) Compartmentalized submodule with flat-packs and individual components stacked inside.

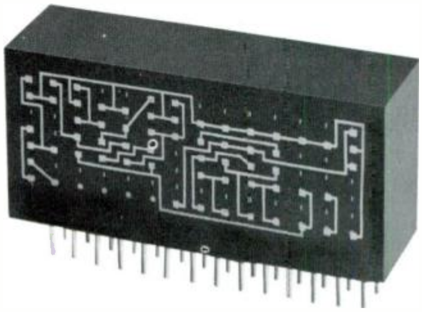


10) Steps in construction of the compartmentalized metal box.

11) Stacked-array submodule holds flat-packs and other components in a specially designed plastic frame structure.



12) Details of spacer used in the stacked-array submodule.



13) Interconnections between flat-pack leads and components are deposited on the sides of the submodule after it has been encapsulated.

among these various components. This method makes the mounting medium an integral part of the circuit and provides good reliability. Since most of the interconnections are made when the components are formed, interconnections will have the same reliability as the components themselves. Production costs can be low because once the circuit is established in tooling, all connections are made simultaneously by the etching process, rather than individually.

When extremely high packaging densities are required, techniques based upon stacking the flat-pack devices on edge (stacked array) will minimize volume. These techniques tend to simplify the system interconnection problem by providing additional interconnection surfaces on the sides of the stacks without a substantial increase in module mounting area. The replacement of an individual circuit package is considerably more difficult with modules of this type than with the planar array type of assembly. However, this is not of great concern because on systems requiring this high level of component density (such as spacecraft or high-performance aircraft), repairs are made by module replacement rather than by component replacement.

A unique version of the "stacked array" method of packaging, developed for use in high-frequency circuits requiring shielding between stages and surrounding equipment, is the compartmentalized structure shown in Fig. 9. The basic assembly structure for this module is a metal box with partitioned compartments, into which the device packs are stacked. Interconnections are made on the top and bottom sides of the assembly by soldering or welding. This configuration lends itself readily to the use of both individual components and flat-pack molecular devices in any combination. The metallic structure acts as a ground shield against r-f radiation and also protects the components. Chemical milling methods are used to fabricate the box structure; steps in the construction of the housing are shown in Fig. 10.

The stacked-array module shown in Fig. 11 is a compact packaging concept developed by Westinghouse Aerospace engineers to provide relative ease of assembly and interconnection, and versatility in handling different component sizes and shapes. Basically, the module consists of a designated number of integrated-circuit flat-packs stacked on edge within a plastic frame. The flat packs are separated from each other by thin spacer blocks, which fit into shallow slots in a base plate. The spacers have molded into them three leads going from side to side, one lead from each side terminating as an output pin on the bottom, and one other lead that can be used as either a crossover or an output pin (Fig. 12). Holes in the bottom of each slot in the base accept the output pins. Interconnecting welds are made on the sides of the assembly, between flat-pack leads and spacer-block leads. The inputs and outputs are welded to the pins that exit from the base. After electrical testing, the complete unit is encapsulated.

With this design, conventional components can be easily accommodated. Small-diameter components can be used in place of a single flat-pack. For larger components, additional spacers can be omitted. A good thermal path for heat transfer out of the integrated circuits is provided by conduction through the spacer to the base to the mounting plane; normally, no special heat sinks are required. For high power levels, a silica-filled encapsulating resin is used to increase heat transfer.

Although this version of the stacked-array module does make exceptionally good use of volume, it is relatively costly to manufacture because each interconnection joint must be made individually. Development work is presently in progress on another version that is smaller, has a shorter production cycle, and will be less expensive to manufacture; a module of this design is shown in Fig. 13. In this version, flat-packs are stacked on edge as in the other design, but the unit is encapsulated before making interconnections. The potted unit is then faced off on the sides from which the circuit leads exit to obtain a smooth surface with component lead ends flush with the surface. The interconnection circuitry is then deposited directly over the plastic surface and the lead cross sections. Methods of interconnection fabrication under investigation include vacuum deposition, conductive paints, electroplating, vapor-phase deposition, pressed dendritic powder, and plasma jet deposition. This design provides the minimum module size for the stacked array of flat-packs. Once the circuitry pattern is established and necessary tooling provided, all interconnections on a module can be made simultaneously with the deposition process, rather than by individual welds. This method will result in a more reliable module that is less expensive to manufacture.

Improving Chip-Package Volume Ratio

These packaging schemes represent a broad cross section of the methods generally used, with variations, through the industry for building systems with integrated circuitry. As such, they are representative of the levels of component density that can be obtained with presently available integrated circuitry. Although other packaging schemes may be devised that allow the packs to be more closely spaced or connected with fewer circuit layers, the disheartening fact remains that the ratio of volume saved by these compression techniques to the overall package volume is insignificant when compared to the ratio between volume of the circuit chip and the volume of its container. Packaging engineers have reached a point on the miniaturization curve that is asymptotic in its approach to minimum size—from a practical standpoint, the maximum density with present integrated-circuit package configurations has been reached.

To achieve further significant size reductions, a greater number of circuit functions must be incorporated into the basic device package. This will be accomplished first by chip improvement, next by the interconnection on a single substrate of a number of circuit chips, and ultimately by a fully integrated system circuit wafer. These areas of investigation are being actively pursued throughout the electronics industry.

Westinghouse ENGINEER
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Central Station Supervised By Digital Computer

A digital computer system is now providing scan, alarming, logging, performance calculations, and malfunction review for the first of two 560-mw (net) turbine generators at the Commonwealth Edison Company's Joliet, Illinois, station. (See photograph, top right.) The new system continuously scans more than 1500 analog inputs. Performance calculations will ultimately include detailed evaluation of the two turbine-generators, the two separate boilers for each generator, and other support equipment such as condensers and air heaters.

The system's Prodac 510 computer, supplied by the Westinghouse Power Control Division, is a high-speed, solid-state, digital unit with a magnetic core memory of 12,288 words and a drum memory of 65,536 words. The system was operating only two weeks after power was available because it had first been checked thoroughly by simulation of the actual operation.

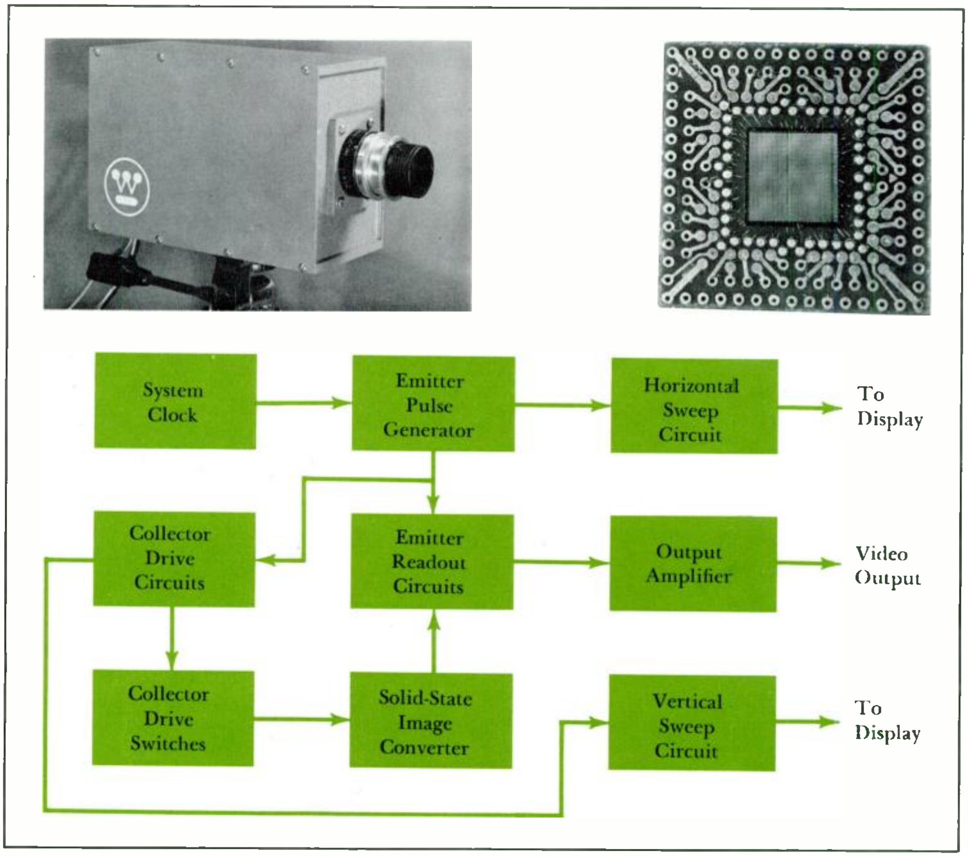
Digital computer system supervises a central generating station.

Compact Camera System Based On Solid-State Imaging Device

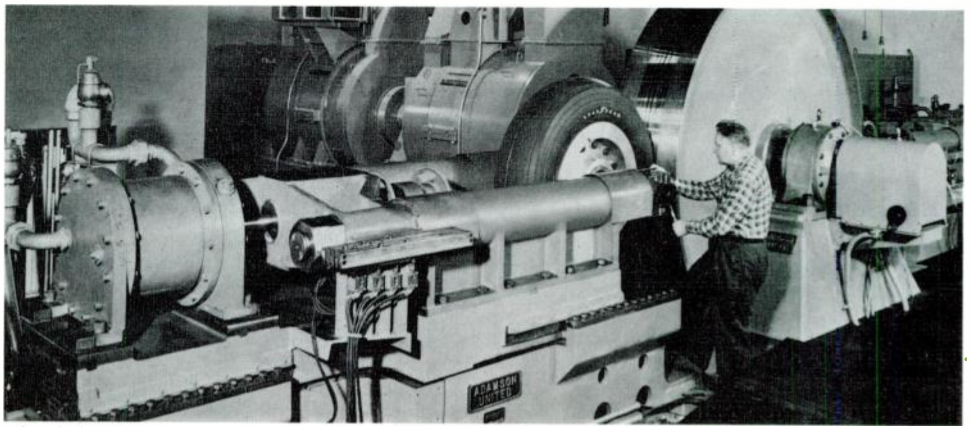
An electronic camera system that uses a solid-state imaging device instead of an electronic tube for light sensing and image conversion has been developed. The electro-optical imaging device, a square mosaic made up of 2500 phototransistors, produces an image with a resolution of 100 lines per inch. (See illustrations, middle right.) The sensitive area of the imaging device measures about 0.5 by 0.5 inch.

Molecular-electronic circuitry is used throughout the camera system to perform the electronic functions necessary to obtain a video signal output. The camera has a standard 16-millimeter lens. Without the lens, the camera measures 6 by 4 by 2¾ inches.

Each of the imaging device's 50 transistor collector structures, which run the length of the mosaic, has diffused into it 50 individual base-emitter structures. The emitters are connected at right an-



Electronic camera system has a tiny solid-state imaging device.



Aircraft tire tester has an improved speed regulator for accuracy.

gles to the collector strips by deposited metal interconnections. Image output signals are obtained by sequentially switching a biasing voltage into each collector row for a time period long enough to get an output signal from the 50 emitter rows. The collector rows are isolated from each other by diffusion.

The camera system was developed by the Aerospace Division of the Westinghouse Defense and Space Center for NASA's George C. Marshall Space Flight Center.

Aircraft Tire Tester Improved With Modern Control System

Aircraft tires have to stand up to increasingly grueling service as landing speeds and aircraft weights increase and as runways and taxiways grow longer. Careful testing is needed to evaluate production tires and to develop improved tires for present and future aircraft. A giant tester for this purpose, developing more than 8500 horsepower at top speed, was installed several years ago at Goodyear Tire and Rubber Company, Akron, Ohio, and has now been improved by substitution of a modern solid-state speed regulator.

The tester (shown at bottom left) is a dynamometer system designed by Goodyear and by Adamson United Company and built by Adamson. Its drive motor was controlled initially by a Westinghouse magnetic-amplifier exciter system. The new speed regulator is a T-100 unit that is simpler, faster, and more accurate than the original controller.

The tester consists essentially of a massive wheel (10 feet in diameter) that simulates the roadway, a motor to drive the wheel, a carriage that holds the tire and forces it against the road wheel, and the control equipment that programs roadwheel speed and tire contact pressure to simulate various landing, takeoff, and taxiing combinations.

Speed of response and accuracy are essential in the regulator system to meet tire engineers' specifications for the complicated simulation programs. With the former regulator techniques, the equipment had to be quite complicated to get sufficient gain to use the output of a curve follower as the motor control cue.

The new T-100 speed regulator is a much simpler multiloop high-gain regulator system consisting of solid-state amplifiers throughout. Because it is fast and easy to stabilize, the regulator follows the programmed reference accurately to provide the desired accelerations, speeds, and decelerations.

Steel Strip To Be Continuously Coated With Aluminum

The first continuous production line for coating steel strip with aluminum by the vacuum-deposition technique is being installed at United States Steel Corporation's Fairless Works. The new processing line is expected to go into operation late this year.

In operation, high-voltage electron guns will vaporize aluminum in a vacuum chamber. The vapor will then deposit on the steel strip, coating it as it moves through the chamber. The line includes entry and delivery looping towers and dual unwind and rewind reels to permit continuous operation of the coating section. Overall responsibility for designing and supplying the vacuum-deposition control and power supply and the drive system for transporting the strip is held by the Westinghouse Industrial Systems Division.

Tandem Aluminum Mill Rolls To Precise Gauge

A new two-stand tandem rolling mill at Anaconda Aluminum Company's plant at Terre Haute, Indiana, delivers 62-inch strip at 2000 feet per minute. The 5100-horsepower mill receives aluminum and aluminum-alloy strip in the range of 0.100 to 0.250 inch thick and delivers 0.015-inch strip.

An automatic gauge-control (AGC) system removes gauge variations in the incoming strip to produce a final product of the desired uniform thickness. AGC is accomplished primarily by adjustment of interstand strip tension. A high-speed screwdown control provides relatively coarse adjustments to reduce large gauge errors; it also operates when tension AGC would exceed its limiting value. Gauge errors are somewhat predictable during speed changes, and these are partially compensated by running the screws at preselected speeds during mill speed changes. The mill can be operated with screwdown AGC only, with tension AGC only, or with both. Thickness feedback signals are provided either by an X-ray gauge or by a micrometer gauge in contact with the strip, at the selection of the operator.

Mill auxiliary control, sequencing, and mill interlocking are concentrated in a director logic cabinet centrally located in the motor room. The main drive control employs thyristor power amplifiers for field regulation.

Airport Transportation System To Eliminate Long Walk

Instead of the usual long walk between central terminal building and airplanes, passengers will take a 40-second ride in air-conditioned vehicles when the new Tampa International Airport opens. The transportation system will operate automatically, much like a modern elevator, for flexibility, safety, speed, simplicity, and economy.

Four lightweight vehicles with pneumatic tires will transfer passengers approximately 1000 feet from the airport building to loading terminals. The vehicles will have doors on each end and will operate back and forth on straight elevated steel structures. They will be 30½ feet long and 8½ feet wide, with a 212-inch wheelbase, and they will be powered by two 60-horsepower dc motors. Guide wheels on the bottom of the vehicle will lock onto a steel I beam in the center of the roadway to guide the vehicle and keep it on the roadway.

Construction of the new airport is scheduled to begin in mid-1966 and to be completed about the middle of 1968. Westinghouse will supply the transportation system and will operate and maintain it for five years.

Supercharged Gas Turbine Serves Industrial Power System

The world's largest gas turbine-generator unit operating in an industrial power system has been installed at Dow Chemical Company's Texas Division, Freeport, Texas. The supercharged unit produces more than 32,000 kw under normal operating conditions.

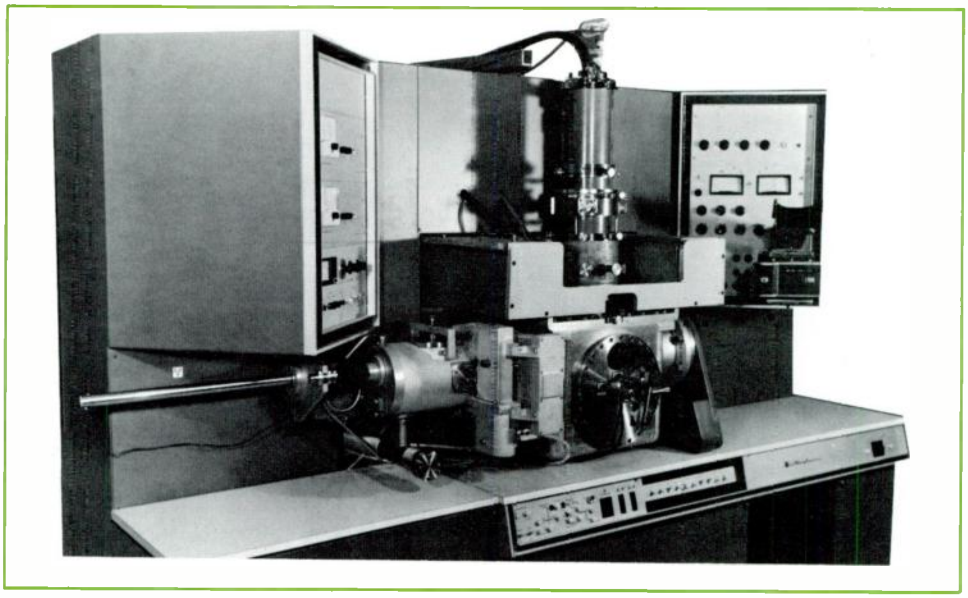
Supercharging, which adds several thousand kilowatts to the net capability of the unit, is accomplished by a motor-driven fan that compresses the combustion air. (The fan motor develops more than 3000 hp.) This air is cooled in an evaporative cooler before entering the turbine at a pressure above 40 inches of water. Supercharging has the added benefit of maintaining turbine-generator capability during periods of high ambient temperature.

Turbine exhaust will be used as combustion air for a large steam generator now under construction. The combined-cycle plant is scheduled for completion in 1966. It will be one of the most efficient power plants ever built, utilizing all of the available oxygen in the turbine exhaust.

The Westinghouse gas turbine-generator unit is the first of four units ordered by Dow. Engineering and construction for the entire project is being performed by Bechtel Corporation, Vernon, California.

Products for Industry

Emergency switch automatically transfers vital loads to stand-by power on loss of utility power. An electronic differential circuit instantly detects undervoltage or loss of voltage and, through relays, initiates load transfer. When regular service is restored, load is switched back to main circuit. Switch is available in capacities to 600 volts ac or 250 volts dc, 225 to 1000 amperes inductive or resistive load, and interrupting capacities to 50,000 amperes rms asymmetrical (higher interrupting ratings on request). Both two- and three-pole units are available. *Westinghouse Standard Control Division, Beaver, Pa. 15009.*



High-magnification scanning electron microscope (above) has three distinct advantages over conventional transmission electron microscopes: it presents the image as an easily understood photographic enlargement of the original, it needs no special sample preparation, and it has great depth of focus. Magnetic lenses focus electron beam to a spot less than 0.25 micron in diameter. Magnification is variable from 40× to 25,000×. Complete installation includes microscope, automatic high-vacuum pumping station, control systems, interlocks, and video amplifier. *Westinghouse Scientific Equipment Department, 7800 Susquehanna Street, Pittsburgh, Pa. 15221.*

Variable-frequency textile-spinning motors (below) embody advanced insulation, heat-transfer, lubrication, and suspension techniques for high performance and reliability. Ratings range from 0.1 to 1 hp and speeds from 5000 to 12,000 rpm. *Westinghouse Aerospace Electrical Division, Lima, Ohio 45802.*

New 161-kv SF_6 common-tank breaker has high current-interrupting ability to protect low side of EHV distribution systems. Rated 20,000 mva, 4500 amperes, it can interrupt 75,000 amperes under any rate of rise of recovery voltage. High interrupting ability was achieved by enlarging blast valve and using a double-flow interrupter. *Westinghouse Power Circuit Breaker Division, Trafford, Pennsylvania 15085.*

Westinghouse ENGINEER Bound Volumes and Indexes

A reminder: Permanent binding of your 1963–1964 issues is now being provided at a cost of $3.75 postpaid if you send your 12 copies to us. We can supply missing issues at 35 cents each, additional, or provide a complete bound volume (we supply the magazines) for $6.00. Bound volumes include index. An index alone for the 1963-1964 issues is available without charge. *Westinghouse ENGINEER, Westinghouse Electric Corporation, P.O. Box 2278, Pittsburgh, Pennsylvania 15230.*

About the Authors

Both **Carl J. Snyder** and **Delbert D. Weers** have had a major part in the development of the magnetic tape-recording system described in this issue. Equipment design has been guided by Snyder, and the coordination of factory developments with customer needs has been the responsibility of Weers.

Snyder received his BSEE from Purdue University in 1936. He came to Westinghouse early in 1946 upon his release from the U.S. Army, where he had served as a captain in the field artillery during World War II. After an assignment on the graduate student course with the meter division in Newark, N. J., Snyder was made a meter sales engineer working out of St. Louis. In 1954, he went to the meter division (now in Raleigh, N. C.) to become manager of meter application.

In 1956, Snyder moved from the sales department to the engineering department to become engineering section manager for test equipment and accessory products. There he began development of solid-state circuitry for impulse totalizing equipment, work that eventually led to the magnetic demand recording system. He is presently manager of the electronic engineering section of the design engineering department, responsible for the design of electronic metering and control equipment.

Weers began college in 1948 on a part-time basis, combining study at Colorado State University with wheat farming. He entered the U.S. Air Force in 1952 and became a transport pilot, assigned to duty in Japan. He returned to Colorado State in 1956 and earned his BS in physical science in 1957.

Weers joined Westinghouse on the graduate student course and became a meter specialist, assigned to the Chicago office. He was reassigned to the Raleigh Meter Division in 1962 to become a meter division representative, assisting Westinghouse field salesmen and customers with metering applications. Recently, he has concentrated on the development of new applications for the automatic tape-recording system.

A. T. Bacheler earned his BSEE at Tufts College in 1941 and has since taken graduate work in electrical engineering at the University of Pittsburgh and the University of Buffalo. He joined Westinghouse on the graduate student course and was assigned to the general mill section of the former Industry Engineering Department, where he worked on the application of electrical equipment to the textile, film, man-made fiber, rubber, and lumber industries. Bacheler transferred to the Systems Control Division in 1950. He is now an application engineer in the Numerical Control Product Line Group, responsible for the application of numerical control and drive systems to machines.

Bacheler is the Westinghouse representative on the EIA numerical control committee. He has been awarded five patents, and he has contributed to the development of adjustable-speed winder drives and the numerical control system described in this issue.

Henry J. von Hollen and **C. F. Currey** are both engaged at the Atomic Power Division in the design and completion of the nuclear plant for the San Onofre Nuclear Generating Station.

The Westinghouse Project Manager, von Hollen, has experience in a series of nuclear plants designed by Westinghouse. His first assignment with the company in 1957 was in preliminary plant engineering, from which he moved to successive jobs as project engineer on the Saxton Reactor, then to the Selni Reactor. He then was promoted to manager of systems development, then to his present position. Henry von Hollen is a graduate of Stevens Institute of Technology, from which he earned his BS in Mechanical Engineering in 1951. He is also a graduate of the Oak Ridge School of Reactor Technology.

Currey originally went to work for the Canadian Westinghouse Company, after graduation from Queens University in 1951 with a bachelor of science degree in Electrical Engineering, and completion of the Westinghouse graduate student course. His first experience was as a control engineer in the Power Rectifier Division. Next he turned to design of switchgear for destroyer escort vessels, but returned to power rectifier design as a development engineer in 1955. In 1958 he transferred to the Atomic Energy Division to work on nuclear reactor instrumentation and control. He was assigned in that year to serve as liaison engineer to the Westinghouse Atomic Power Division, where he worked on a broad variety of design studies. In 1960 he joined the Division on a permanent basis. He assumed his present position as project engineer for the San Onofre Project in 1963.

As manager of Systems Technology research and development at the Westinghouse Research Laboratories, **Dr. Kan Chen** is responsible for a variety of systems analysis and development projects in the areas of process and production control, operations research, management decision theory, and system planning. Among the projects he has been responsible for or contributed to are computer control of a continuous pulp digester, computer control of basic oxygen furnaces, simulation and control of transportation and production systems, and dynamic modeling and control of central stations.

Dr. Chen graduated from Cornell University with a BEE in 1950. He earned his SM and ScD degrees at Massachusetts Institute of Technology in 1951 and 1954, respectively, and then joined Westinghouse. He has served as an adjunct professor at the University of Pittsburgh and as a visiting professor at Stanford University. Dr. Chen's language interests are not confined to the new computer languages but include conservation of an ancient language; away from his desk, he is responsible for the Chinese Language School of Pittsburgh.

Dr. E. Y. Kung is a senior research engineer in the research and development department of Jones & Laughlin Steel Corporation. He earned his BS in engineering science at North Central College, Naperville, Illinois, in 1954, a BS in chemical engineering at the University of Illinois the same year, and a PhD in chemical engineering at Carnegie Institute of Technology in 1959. He has also taken courses in automatic control and in operations research.

Dr. Kung joined J&L in 1959. His first assignment was to develop a mathematical model of the continuous annealing process and to devise a computer control for an annealing line. In his present post, he directs the department's activities in systems analysis, which includes computer simulation and analysis of process control and integrated plant control. He is a senior member and director of the automatic control systems division of the Instrument Society of America.

P. B. Skov earned his BS in physics at California Institute of Technology in 1960 and his MS in electrical engineering there the following year. He is now at Stanford University in the Westinghouse-Stanford systems engineering internship program, working on a PhD in electrical engineering that he expects to receive this year.

Before joining Westinghouse in 1963, Skov had worked at summer engineering jobs with Douglas Aircraft Company, Inc.; North American Aviation, Autonetics Division; Space Technology Laboratories; and A. C. Spark Plug Division, General Motors Corporation. He was responsible for the Westinghouse part of the joint mill scheduling study with Jones & Laughlin Steel Corporation described in this issue.

Henry G. Carter, Jr., obtained his BEE degree at Auburn University in 1942. During World War II, he served in the U.S. Army as a field artillery officer and was discharged a captain in 1945. He returned to Auburn to earn a BME degree in 1946.

Carter joined the Westinghouse Aerospace Division in 1955 as a design engineer on servomechanisms and components for airborne fire-control and guidance systems, specializing in hydraulic-power devices.

In 1962, Carter was made a senior engineer in the mechanical design and development section of the high-density packaging group to develop subminiature packaging techniques. He has had mechanical design responsibility for such equipment as the telemetry encoders in the S-52 and FR-1 satellites. His stacked-array submodule design, described in this issue, won an "Excellence in Design" award at the 1964 National Electronics Packaging Conference.

Brushless Excitation

This 8,000-horsepower synchronous motor is shown during final inspection at the Westinghouse Large Rotating Apparatus Division, East Pittsburgh, Pennsylvania. The motor will drive a pulpwood grinder at a Kimberly-Clark Corporation plant. This unit is the first of its size in the paper industry to receive field excitation from a brushless exciter (foreground) rather than a motor-generator set. With this arrangement, the ac exciter, rectifier, field-discharge resistor, and synchronizing control are all mounted on the rotating shaft with the synchronous-motor field, thereby eliminating the need for moving current-collecting parts.