THE RW-300 PORTABLE PROCESS ANALYSIS UNIT

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System Description

I. SUMMARY

Introduction

The RW-300 portable process analysis unit represents a new approach to the problem of analyzing and improving the performance of a chemical or industrial plant. It makes available for the first time in a mobile research unit the powerful capabilities of the RW-300 Digital Control Computer. Specifically, the portable unit will contribute in the following ways to an analytical study:

1. As a fully portable unit, including a universal input-output system, it can be installed at a plant site at minimum expense for the duration of a study.

2. With the RW-300 computer connected on-line, the unit provides a complete data collection and reduction facility for the exclusive use of the study team.

3. The output capability of the RW-300 will greatly facilitate the scheduling of tests and the development of control equations for the process.

4. The portable unit offers extreme flexibility through simple program modification and, where desired, through the addition of magnetic tape or expanded input-output capacity.

The combination of these qualities makes this portable unit an extremely powerful and flexible process-analysis research tool. Significant returns should be realized in increased process knowledge, savings in computer time, and reduced professional manpower time.

The RW-300 portable unit is available on either a lease or purchase basis.

Equipment Comprising the Portable Process Analysis Unit

The RW-300 portable process analysis unit is contained in a 28-foot semi-trailer for easy removal from one site to another. Air-conditioning equipment and a motor generator set is built into the trailer to ensure maximum system performance. Virtually any desired configuration of input-output equipment can be incorporated into the unit; for illustrative purposes, a typical system has been outlined in Section II of this report. It includes 128 analog inputs and 18 outputs, plus 32 mounted pneumatic-to-electric and 4 electric-to-pneumatic transducers. Also provided with the typical system would be digital inputs and outputs for display and control; a Flexowriter and logging typewriter; an operator's control panel; and miscellaneous peripheral equipment.

Potential Uses

The RW-300 portable unit will perform a variety of functions useful in process analysis (see Section III). These include the following:

1. Data Collection. Measurements from 128 (or, through expansion, up to 1024) measuring instruments can be automatically sampled and recorded by the RW-300. Readings can be scaled, edited, smoothed, and printed or punched out either continuously (30 to 150 samples per minute) or periodically. Optional magnetic tape units would make possible faster collection of larger volumes of data for analysis of the dynamic characteristics of the process. The memory and computational abilities of the RW-300 will make it possible to sort the data that has been collected to provide a time history of any variables required. Processed data can be put out in any format convenient for later analysis on, for example, IBM 605 or Datatron 205 machines.

2. Output Functions. The RW-300 can generate 18 (through expansion up to 128) analog outputs for closed-loop control. Thus, an analytical test can be systematically altered while still in progress, with the resuls of each change accurately recorded. Plant variables can be changed in prescheduled steps and, as a control model is developed, the computer can be instructed to calculate and report its own schedule of changes based upon process response. In this way, the portable unit can be made to refine automatically its own control equations.

3. Analysis of Results. Following, or in some cases actually during, a plant test, the unit can be used to perform correlation and regression analyses of the collected data. By this means, a great deal of manual labor can be saved and meaningful results can be obtained with a minimum of delay. An extensive library of analytical subroutines is available to users of RW-300 systems.

By combining the features of data-acquisition and data-processing systems, in addition to providing the capability of closed-loop control, the portable unit can contribute in many ways toward reducing the time and professional manpower required to conduct plant analyses. The experienced TRWP process analysis, project engineering, and programming groups will be available at all times to assist in fully utilizing the advanced capabilities of the portable system.

System Expansion

Within the confines of the semi-trailer provided, the RW-300 system can be expanded to include up to 1024 inputs and 128 outputs, 260 P/E transducers, and a wide variety of peripheral equipment, including magnetic tape units, display panels, x-y plotters, high-speed punters and punches, etc. Additional E/P transducers may be housed either inside or outside the trailer. A 15,500-word magnetic drum memory can be provided if required. In any of these areas, expansion can be accomplished through straightforward field modifications. Many additional system modifications can be accomplished without any equipment change whatsoever, simply through rewriting the program stored in the RW-300.

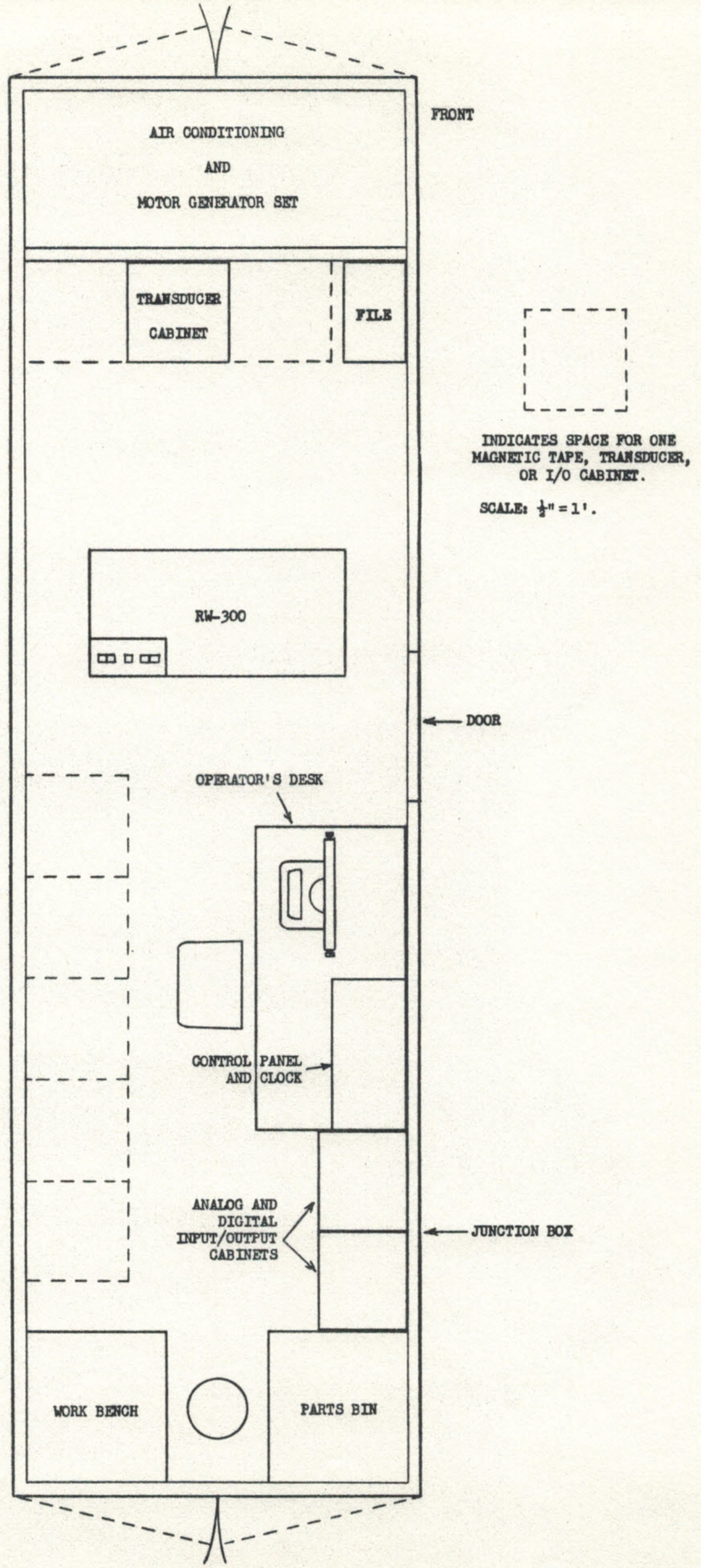

Figure 1. Floor Plan for RW-300 Portable Process Control Unit.

II. DESCRIPTION OF A TYPICAL RW-300 PORTABLE UNIT

General

This section contains a description of a typical portable unit, with an average input/output system. It should be emphasized, however, that considerable flexibility is available to meet specific customer requirements in either the layout or the equipment configuration of the RW-300 system. Some of the equipment modifications possible are outlined in Section III below. A more detailed description of the RW-300 may be found in Appendices A and B.

Equipment Included in the Basic Unit

1. RW-300 Digital Control Computer with 8000-word memory, plus Flexowriter with tape and edge-punched card input and output.

2. Analog-Digital Converter and Analog Input-Output System, composed of sixty (60) thermocouple inputs with necessary reference junction, sixty-eight (68) interchangeably high or low-level d. c. voltage inputs, eighteen (18) d. c. voltage outputs, thirty-two (32) pneumatic-to-electric transducers and four (4) electric-to-pneumatic transducers.

3. Digital Input-Output System for various on-off indications and actuations, program control, and display composed of 36 bits of digital input and 18 bits of digital outputs.

4. Peripheral Equipment consisting of:
   a. Operator's panel and time-of-day clock.
   b. An IBM logging typewriter (30" carriage) and decoder.
   c. "Watch-dog" timer (automatic program restarting feature).

5. Semi-trailer, with above equipment completely mounted, including three-ton refrigerated air conditioning unit, four-drawer file cabinet, chair and stool, emergency light, fire extinguisher, automatic gas alarm, motor-generator set, cables, intercom outlet and circuit breakers.

Physical Layout of the Unit

The physical layout of the RW-300 system is indicated in Figure 1. As shown here, the system will include two input-output cabinets and one cabinet for pressure-to-electric transducers, in addition to the equipment specifically listed above. The input-output cabinets will include logic elements, amplifiers, the thermocouple reference junction, the watch-dog timer, and analog and digital junction boxes. Equipment will be packaged in each type of cabinet so as to require access for maintenance only from the front. Access to the RW-300 itself will be provided on all sides.

Comfortable working space will be made available at the operator's desk and workbench. Permanently mounted on the operator's desk will be the operator's control panel and the digital time-of-day clock display. The Flexowriter and logging typewriter will also be located here. Adequate space for system expansion will be available, as indicated by the dashed lines in Figure 1 and as discussed in Section IV of this report.

Four electric-to-pressure transducers will be packaged in a separate module located inside the plant, probably in the control room. Control outputs will be conveyed to the control room as d. c. signals and will be converted to pneumatic signals at this point as required. For full closed-loop control, controllers must be available which are capable of being automatically set, either by electric or by pressure signals.

Equipment Dimensions

1. Semitrailer- 28 ft. x 8 ft. x 8 ft. (interior dimensions, with 2 ft. high cable conduit and storage space beneath).
2. RW-300- 57 in. x 30 in. x 37 in.
3. Input/Output or P/E Transducer Cabinet- 24 in. x 24 in. x 84 in.
4. E/P Transducer Module- 20 in. x 24 in. x 24 in.
5. Operator's Desk- 73 in. x 37 in. x 30 in.
6. Operator's Control Panel- 40 in. x 17 in. x 13 in.
7. Magnetic Tape Transport or Buffer Cabinet- 24 in. x 24 in. x 72 in.

Characteristics of Signal Conditioning Equipment Provided

A. Transducers

A number of standard commercial transducers, both of the current and voltage type, are compatible with the RW-300. The instruments described here are typical models used in past installations, and are of the general type which will be employed in the portable process control unit.

1. Input Transducers. Pressure-to-current transducers, such as Minneapolis-Honeywell's Industrial P/I model, are normally employed for the sake of maximum accuracy. The actual 0-10 volt d.c. input required by the computer is then taken off a 500-ohm precision resistor, with an overall accuracy of $\pm$ 0.25%. The operational characteristics of the M-H transducer are as follows:

Air input	3-15 psig
Output	4 to 20 ma dc
Power supply	42 $\pm$ 2 V dc
Operating distance	Up to 12 miles (with #18 AWG wire)
Total external load resistance	800 ohms maximum
Operating limits	
Ambient temperature	-40 to +150°F.
Relative humidity	10% to 100%

2. Output Transducers. The output signals from the RW-300 can be obtained as either 0-10 volt or 0-5 ma. signals. Again, current-pressure transducers are favored; for example, Taylor Instruments' Model 701 TF 113. Its operational characteristics are as follows:

Zero Suppression	4.5 to 5.25 ma.
Accuracy	0.5%
Linearity	0.3%
Ambient Temperature Error	1%/50 F. max.
Air Consumption	.25 SCFM

B. Thermocouple Reference Junction

A Pace bridge-stabilized reference junction, with up to 100-channel capacity, will be supplied with the basic system. Any of the common varieties of measuring junction can be used in conjunction with this instrument. Either two or three-wire reference junctions can be furnished on request. The Pace junction has the following characteristics:

1. Temperature range available- 25° above ambient to 250°F.
2. Temperature stability- ±0.20°F.
3. Temperature uniformity- ± 0.10°F.

Scaling and linearizing are normally performed digitally by the RW-300, with no consequent loss of accuracy.

III. USES OF THE RW-300 PORTABLE UNIT

General

Since it incorporates all the capabilities of standard data-acquisition, data-processing, and process control units, the RW-300 portable unit can be of use in every phase of process analysis. This section describes some of the possible functions of the portable unit in data handling and control. Some of the subroutines available for use with the RW-300 are also indicated here.

Data Collecting Functions

The following items are indicative of the range of data collecting functions that can be performed by the RW-300 system:

1. Continuous acquisition and printout at the fastest speed possible. Estimated operating rate: 30 to 50 samples per minute, each with four-decimal-digit precision. Inputs may be any mixture of temperature, pressure, or flow readings, as well as signals from such on-stream analyzing devices as densitometers, chromatographs, infrared analyzers, etc.

1a. Continuous acquisition and punchout, similar to 1 above. A rate of 40 to 150 samples per minute can be achieved in this mode of operation, using a high-speed paper tape punch.

2. Periodic data logging, at a rate of 200 to 500 points per hour. Computing functions can be performed between logs, under this system. On-demand logs can also be provided for.

3. Fluctuation measuring. The computer can record at any desired intervals (e.g., two, five, or ten minutes) the high, low, and average value for any variable. The data output can thus be smoothed to eliminate random fluctuations.

3a. Fluctuation quantizing. The computer can prepare a distribution spectrum for a variable, showing the percentage time spent in each assigned region of its range.

4. Human editing, using multichannel oscillographs or x-y plotters. The rate of acquisition of sample can be varied at will for each input channel, based upon the results shown on the oscillograph or plotter.

5. Automatic editing, based upon observed instrument readings. The computer can be programmed to observe its own input data and print out only significant occurrences-for example, an out-of-limit variable or equipment breakdown. This technique would maximize the on-line computing time available.

6. Magnetic tape option. Computer-controlled magnetic tape units can be supplied that would permit faster data acquisition and increased speed in off-line data reduction. Magnetic tape is of particular value in preparing time histories of variables, to assist in analyzing process dynamics.

Output Functions

By connecting the computer outputs provided with the RW-300, process variables can be automatically adjusted in precise increments to yield desired information. A quantitatively exact record of the time and magnitude of each change would be kept, together with the results observed. With the development of a preliminary control model, the computer could be programmed to enforce the control procedures called for, compare observed with predicted results, and modify coefficients in the control equations to improve plant operation. The results of this kind of computer analysis can be of great benefit, either for improving manual operation or as the necessary first step toward the installation of a permanent computer control installation.

Analysis of Results

Using the portable unit, test results can be immediately analyzed and used to determine the course of further investigations. The data accumulated during the day's run can be processed automatically during the night shift, yielding results for use the next day. In some cases, where sampling rates are low, analytical computations can actually be performed during the data collection period itself. Correlation and regression programs, some of which are listed below, have been developed for use with the RW-300. Specific techniques have also been developed, through work on a number of RW-300 installations, to determine process time lags and transfer functions of variables.

The RW-300 program library contains completed working programs for linear and non-linear regression of up to 10 variables, with up to 50 samples per variable. Programs for computing cross- and auto-correlation and for computing statistical signficance for independent variables are also available. A number of programming packages have been prepared to assist in particular aspects of work with the RW-300. These include OPUS (Optimum Programming Using Symbols); SAFARI, a floating point scientific package with built-in mathematical function subroutines; and a data processing package for easy communication with the computer. These and other programs available for the RW-300 will be supplied free of charge for users of the system.

IV. SYSTEM EXPANSION

General

The purpose of this section is to outline the possible areas for expansion of the typical RW-300 system described in Section II. The only unusual constraint upon such expansion would, of course, be the physical dimensions of the semitrailer. Without decreasing the allotted access and working space shown in Figure 1, a total of seven additional standard-sized cabinets could be installed. This would make possible the degree of expansion discussed below.

Additional Analog Inputs and Outputs

The RW-300 has a maximum capacity of 1024 analog inputs and 128 outputs. Up to 1024 high-level inputs could be incorporated into the portable unit without occupying any additional floor space. Additional low-level or thermocouple inputs would probably require expansion into an additional input-output cabinet, which would provide accommodation for approximately 300 to 400 such signals. Still further cabinets could be added if necessary.

A total of 36 analog outputs, 18 more than the number currently suggested, can be incorporated into the RW-300 chassis. Expansion beyond this total would require the use of part of an additional input-output cabinet. Two additional cabinets would allow expansion to include the maximum number of outputs and an input total of from 500 to 1000 signals.

Additional Digital Inputs and Outputs

As many as 554 digital inputs or digital outputs can be supplied for the unit. The expansion to maximum digital capacity could be achieved with no more than one additional input-output cabinet to house the necessary circuitry.

Additional Transducers

Pressure-to-electric (analog input) transducers will be packed 32 to a cabinet; thus, an additional 224 transducers could be included in the process control unit, assuming no other equipment expansion, without any sacrifice of working space. Incorporation of a magnetic tape unit (two cabinets) or a substantial increase in low-level or digital signals (one or more cabinets) might, of course, reduce either the transducer or workbench space available.

Electric-to-pressure (analog output) transducers will not normally be permanently mounted in the trailer, but will be located inside the plant. Accordingly, there will be no space limitations on the total number of these devices. Up to 128 transducers, packaged four per module, could be provided.

Magnetic Tape Unit

A magnetic tape unit, including core buffer and tape transport, could be installed conveniently inside the semitrailer. Up to three additional transports could also be included, assuming no further equipment expansion.

Increased Memory Capacity

An expanded magnetic drum memory, providing 15,500 18-bit words, could be furnished for the RW-300 system without adding to the space requirements outlined previously.

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Appendix A --
Description of the
RW-300 Digital Control Computer

Appendix B --
Reliability of the RW-300

DESCRIPTION OF THE RW-300 DIGITAL CONTROL COMPUTER

GENERAL DESCRIPTION

The RW-300 Digital Control Computer represents a major advance in the field of automatic control. Designed on the basis of requirements developed in systems analyses of actual processes in several oil refineries and chemical companies, the RW-300 has been engineered specifically for automatic control of continuous or batch industrial processes, for use as a computing data logger, and for pilot plant and test facility operation.

Process Control

When considered from the standpoint of on-line process control, the RW-300 is the first integrated digital computer capable of exercising comprehensive control over a complete process unit by:

1. Accepting automatically analog and digital inputs from all significant process instruments and from the process operator.

2. Concurrently with the conversion of analog inputs and outputs, performing the computations required for interpreting and analysing the input data.

3. Calculating the values of the important process variables.

4. Calculating the effect on process operation of changes in these variables.

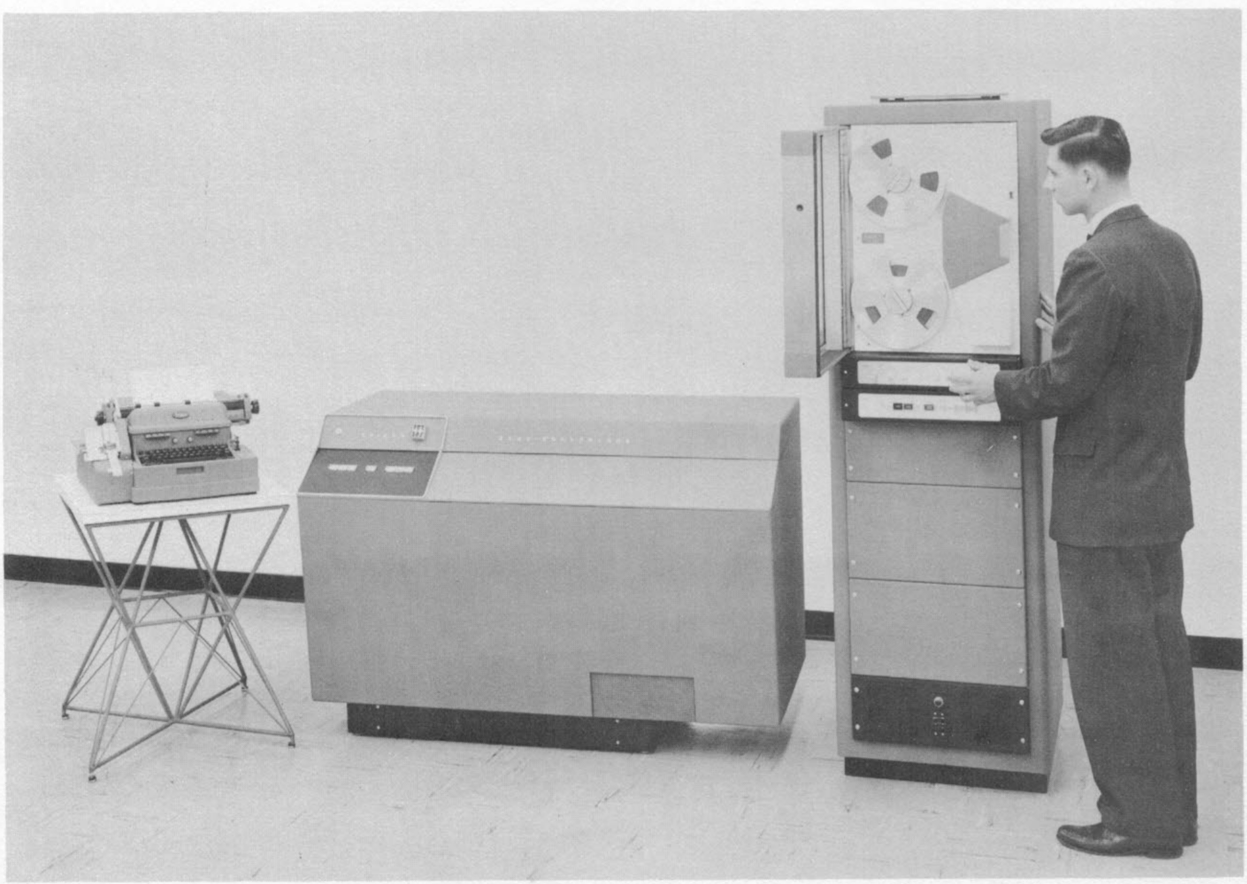
5. Calculating the new values of the variables to be controlled.

6. Evaluating on a continuous real-time basis the cost, quantity produced, and quality of the end product; and

7. Comparing the measured and computed process quantities with predetermined and/or computed standards.

Figure A-1.

The RW-300 upright model (right) and console model (below, with magnetic tape unit).



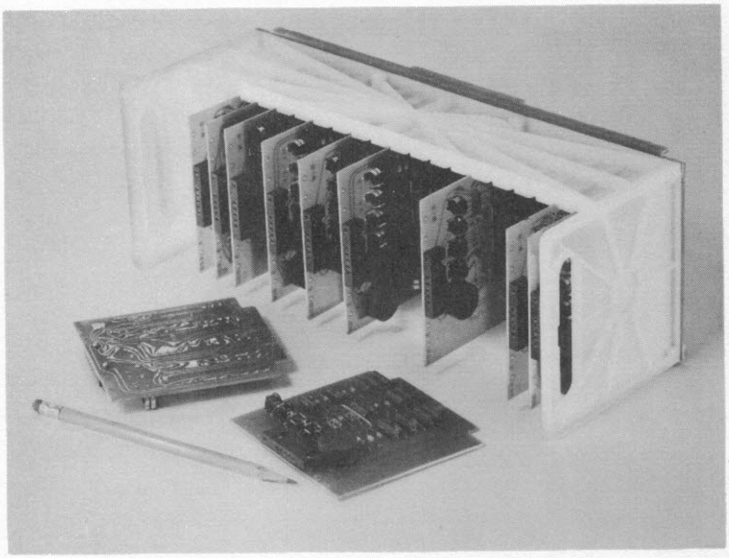


Figure A-2. Plug-in Module and Insert Boards for the RW-300.

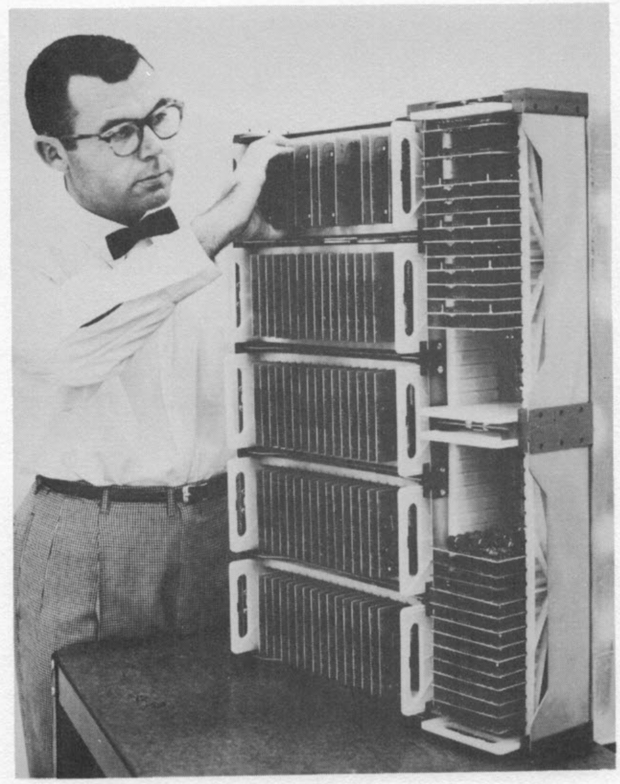


Figure A-3. Sub-frame showing mounted Modules.

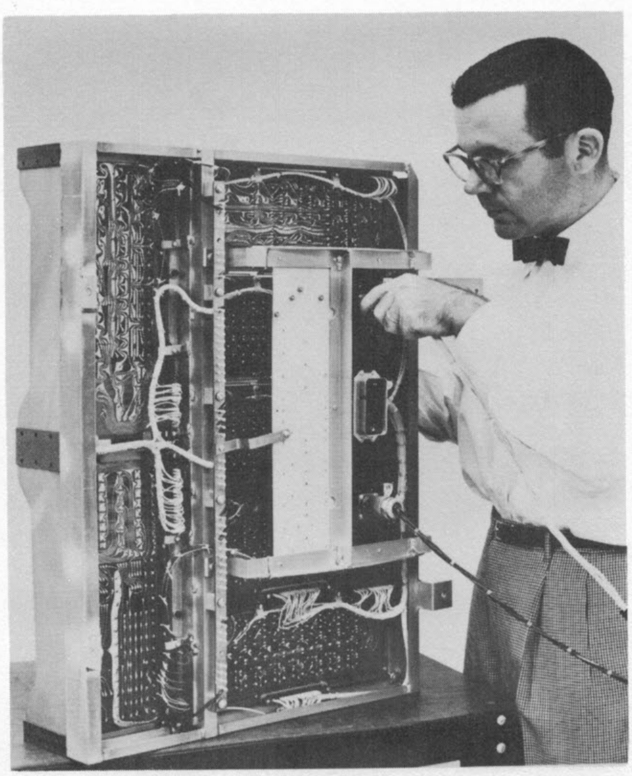


Figure A-4. Etched wiring of Modules shown in rear view of Sub-frame.

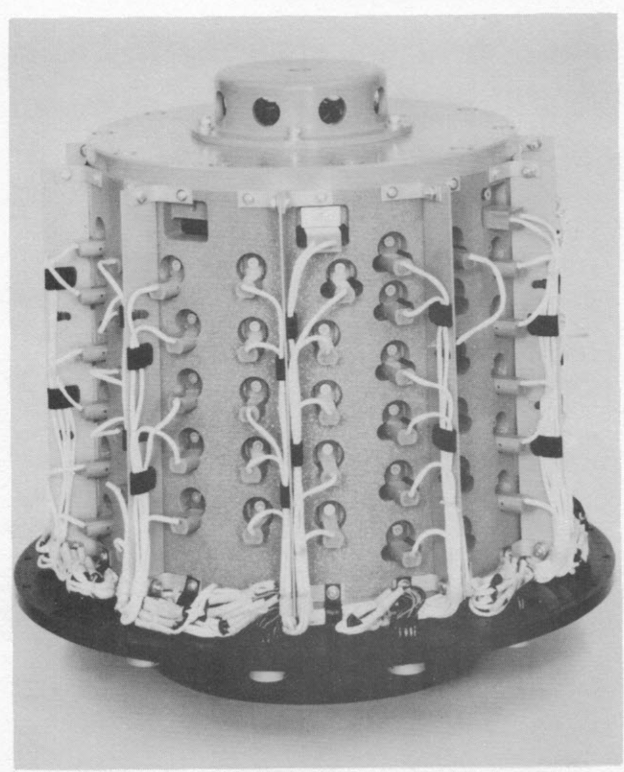


Figure A-5. RW-300 Magnetic Drum memory unit.

The RW-300 then uses the results of the above to automatically manipulate the process controls. Thus it is able to maintain process operation at the optimum economic point, and maximize operating profit.

As a source of process information, it can also be used to:

1. Monitor changes in process conditions and instrument responses and automatically and on demand actuate audible, visual, or printed signals to indicate abnormal or unsafe conditions.

2. Record in printed form data concerning process operation for process analysis and for production records.

3. Record process data on punched paper tape, punched cards, or other forms for use in other automatic data processing systems.

4. Perform, on a time-sharing basis with other operations, statistical analyses and summaries of process data.

Computing Data Logger

Used as a computing data logger, the RW-300 can do more than just record process instrument readings. It can interpret these readings and print out operating guides. Also, the computer can scan process variables and activate an alarm when a predetermined limit is exceeded. It will also detect instrument failures by performing a series of complex "reasonableness" checks, and undertake statistical analyses and computations necessary for evaluating recorded data.

Closed Loop Test Control

Significant savings in test time are possible through the ability of this machine to program the test routine and then take advantage of feedback information from the test measuring instruments. This feedback, either in raw form or after computation, is used to alter the original routine. It is able to perform this closed loop control by:

1. Accepting and recording on its magnetic drum the pre-established test routine and associated programs through punched paper tape.

2. Activating and calibrating test instrumentation through either the analog or digital outputs and inputs.

3. Actuating the analog or digital control devices necessary to start and continue the test.

4. Automatically accepting analog and digital inputs from test measuring instruments and from the operator.

5. Concurrently with the acceptance of these inputs, performing calculations required for interpreting and analyzing input data.

6. Comparing the measured and computed quantities with predetermined and/or computed standards.

7. Calculating the new values of control functions.

The RW-300 then uses these results to:

1. Remanipulate automatically the control actuators so as to maintain operation at the desired conditions.

2. Monitor changes in test conditions and instrument responses and automatically and on demand actuate audible, visible, or printed signals to indicate abnormal or unsafe conditions.

3. Reschedule the test conditions on the basis of partial test results so that more meaningful test data can be obtained.

4. Record raw or processed data as indicated below under "Real time test data processing."

In performing these functions the RW-300 could sequence through tests which produced the expected results very rapidly. However, when unexpected results were encountered the RW-300 could recycle a portion of the test, hold the test at that operating level and allow manual examination, or better yet call upon analytical subroutines which examined results in detail and required an alternate approach.

Real Time Test Data Processing

In many cases (within the limitations of speed and complexity) the RW-300 can, in addition to the control functions described above, perform the processing of the great mass of test data not already considered for control purposes. Quite often the advantages of having computed data available during the test is reason enough for an RW-300 installation. This might serve as the first step to a test control system which would be added after sufficient knowledge becomes available. In this case there are no computer outputs directly connected to the test, but test analog and digital results are still fed directly to the computer. Calculations are handled in the same manner as above; the RW-300 is used to:

1. Record in printed form data concerning test operation.

2. Record on either digital or analog X-Y plotters significant real time, quick-look data.

3. Record data on punched paper tape, punched cards, magnetic tape, or in other forms.

4. Perform statistical analyses and summaries of test data on a time sharing basis with other operations.

In conjunction with the RW-300 magnetic tape unit, capacity for handling extremely large amounts of data has become available for the first time in a medium-size computer. The magnetic tape capability extends the RW-300's memory capacity, makes possible higher speed scanning and enables more complete test data to be accumulated.

OPERATING PRINCIPLES

How the RW-300 operates in a typical system will be discussed from the standpoint of a common application, i. e., the control of continuous or batch processes such as are found in the petroleum refining, petrochemical, chemical, metal, glass, food, paper, and similar industries.

Prior to the installation of the computer, a thorough study is made of the process so as to evaluate and to devise methods of measuring the parameters which influence the resulting output. From this study evolves an equation or group of equations which define how the optimum operating point is related to all the significant variables.

The RW-300 is then programmed to solve these equations.

Process temperatures, pressures, compositions, etc., obtained from process instruments, are first fed into proper transducers. Electrical analog outputs from the transducers are sent directly to the computer.

In the analog-digital conversion equipment, an integral part of the RW-300, these electric analog signals are converted into digital quantities. The computing section uses these quantities to perform the calculations necessary to determine what values of the operating variables will optimize the process output.

The results can be converted back to analog quantities and used to make adjustments directly on the process or they can be released digitally on punched tapes or in typewritten form.

COMPONENTS

Input

1. Analog Input
A broad path of communication between the computer and process or test stand instrumentation is provided by virtue of the several hundred analog inputs possible (up to 1024 in standard systems). The standard signal accepted by the analog input system is a dc voltage. Transducers to convert pneumatic, ac electric, or mechanical instrument signals to this form can be supplied.

2. Digital Input
The basic unit of the RW-300 includes 18 one-bit digital inputs and a Friden Flexowriter with associated paper tape reader (ten characters per second). For high speed digital input, a Ferranti punched tape reader (60 characters per second) may be used. Up to 540 extra one-bit digital inputs are also available if required.

Analog-Digital Converter

The d. c. voltage-digital converter is switched automatically among the various inputs and outputs and operates directly into the magnetic drum storage. After an input conversion, the digital number is written into its proper storage location. These functions are independent of the rest of the computer. They do not need to be programmed and are performed concurrently with the control computations.

The complete conversion, including reading from storage (for outputs) or writing into storage (for inputs), requires only two word times or 260 microseconds; hence it is possible to operate at relatively high input-output frequencies. A typical switching rate, however, is an average of one input per drum revolution.

The converter has an inherent resolution of one part in 1,024 and an accuracy of plus or minus 0.1 per cent.

Storage

A magnetic drum 9 inches in diameter, 9 inches long, and rotating at 3600 rpm is used for storage. It provides 7936 words of general storage, arranged in 62 tracks of 128 words each, giving an average access time of 8.3 milliseconds and a word time of 0.13 milliseconds. In addition, there are 16 words of fast access circulating memory (revolver) available, with an average access time of just over one millisecond. The one-plus-one address instruction system in which the address of the next instruction is specified in the current instruction ensures that in most programs the average instruction time is significantly less than 8.3 milliseconds.

The 62 tracks of general storage are divided into two parts:

1. Eight tracks in which data can be recorded under program control. In systems where large amounts of data must be digitized, 16 writable tracks may be provided.

2. Fifty-four tracks which usually contain the stored program, including constant data, and which cannot be written into during computer operation. This prevents accidental altering of the program. Naturally the information in these tracks can be revised when necessary. This can be done by the operator by performing functions which are neither complicated nor time-consuming, yet are not such that can be executed inadvertently.

An expanded drum including 15,360 words of general storage arranged in 120 tracks, plus two revolvers, is also available for a slight extra charge.

Output

1. Analog Outputs

   Up to 128 analog outputs are available with either model of the RW-300. The basic output signals are d.c. currents or voltages which can be transduced into pneumatic or mechanical signals to manipulate controller setpoints, valves, or other control devices so as to obtain closed-loop control.

2. Digital Outputs

   A Friden Flexowriter, with associated paper tape punch, is standard equipment. Logging typewriters and high-speed punches can be supplied. Up to 558 digital output channels are available for operating these machines, or for control or display purposes.

Instruction System

The RW-300 uses an 18-bit word length, and specifies binary numbers by using 17 bits to represent the absolute value and one bit to represent sign (plus or minus). Decimal numbers and alphabetic information may be handled on the digital input-output equipment with the aid of sub-routines.

The instruction system consists of 20 basic commands which permit a total of more than 150 distinct operations. Each instruction occupies two word lengths. A definite number of bits are used to specify the operation to be performed, the address of the operand, and the address of the next operation. The remaining bits can be used to specify length of shift, number of digits participating in a multiplication, execution time, etc.

The 20 Operation Codes permit control of all digital input-output equipment, the execution of all the basic arithmetic operations, transfer of control on zero, overflow, and negative, and other logical manipulations.

EXECUTION SPEEDS

Execution speeds of these operations are, of course, variable depending on the location of the operand and of the last instruction. Several typical execution speeds are given below, assuming optimum location of the instruction and the operand.

Add or subtract	0.78 ms
Multiply	2.99 ms
Divide	3.12 ms
Transfer	0.52 ms
Load	0.65 ms
Store	0.78 ms

SPECIAL DESIGN FEATURES

The RW-300 has been designed and packaged so that it is rugged, compact, and easy to maintain. Figure A-1 shows (bottom) the console model of the RW-300, which is the size of a small desk and weighs under 600 pounds. The upright model (shown at top) is identical electrically to the console model, but is capable of being air purged. It weighs just 700 pounds and is available only to special order.

The computer is built on a modular basis. The fundamental unit is the insert card which contains an active circuit (Figure A-2). All inserts are standard size phenolic boards embodying the latest improved techniques in printed circuitry.

A number of insert boards are plugged into each module (Figure A-2), which, in turn, use a new post-form technique to make a printed circuit plug-in connection possible between the module and the sub frame (Figure A-3). The flush etched wiring on the back of the modules is shown in Figure A-4 as mounted in the sub-frame.

The completed modular construction is shown in Figure A-8. It is apparent that each module can be readily removed from the sub-frame for servicing, practically eliminating computer down time in the event of failure.

The magnetic drum (Figure A-5) is designed to be rugged and reliable. It uses specially designed magnetic reading and recording heads which operate with fully transistorized circuits.

CIRCUITRY

The use of semiconductor devices, transistors, and diodes throughout the computing, central storage, and conversion circuits contributes to the RW-300's small size, low power consumption, and long life. An important by-product of this design, is that no special air conditioning is required to cool the computer, since it generates virtually no heat itself; but it is recommended that it be installed in an air-conditioned room, because its components will function considerably longer in a cool environment. Naturally the amount of air conditioning required is a great deal less than is necessary with other computers which generate considerable heat of their own.

Logical information in the RW-300 is conveyed in the following manner. All active elements are dynamic, continually producing a square wave output. Two computer-generated synchronizing signals are associated with this a.c. wave. By changing the phase relationship between these two signals, the wave can be made to carry different logical information. By sampling the wave for voltage level with time, this information can be retrieved and interpreted throughout the computer. This signal representation used in both the magnetic drum storage and the computing and control circuits contributes to the reliability and simplicity of the computer. Being a.c. in nature, the signal eliminates the requirement of d.c. stability, always difficult to combine with high frequency response, and permits the use of transformer coupling so that the impedances of various circuit elements are easily matched to allow each element to operate at its most efficient level.

The square wave character of the signals makes possible a simple and reliable timing and synchronization system, invariably a problem with other types of computer signals. The use of the same wave form in the magnetic drum storage as in the computing circuits makes the matching of the storage reading and writing to the computing circuits especially simple.

In addition to the use of the above-described special signal type, the circuit designs have been carried out so that they will give long, continuous, trouble-free operation in the normally difficult environments of industrial process plants.

Only components meeting rigid qualifications are used. The circuits are designed to be insensitive to variations in components, to external electric disturbances, and to temperature variations.

OPERATIONAL FEATURES

The RW-300 is designed so that it is easy to operate. The control panel is free of extraneous knobs, lights, and buttons. It contains only six lighted push buttons and one indicator light. The push buttons are (labeled by the functions they perform):

POWER ON	START (PROGRAM)
POWER OFF	STOP (PROGRAM)
LOAD (PROGRAM)	RESUME (PROGRAM)

The additional indicator is:

STAND-BY (indicating that power is on, the drum is coming up to speed, the power supply is being warmed up, and the computer will soon be ready to operate)

These push buttons and indicator light, plus the digital input-output equipment are all the operator needs to operate the RW-300.

Programs and data are loaded into the memory simply by inserting a properly prepared punched paper tape into the tape reader, plugging the input cable into the receptacle for the proper tracks, and pushing the LOAD button. Loading of the information on the tape then takes place under control of the loading process.

The control panel has been purposely separated from the maintenance panel so as to emphasize the different functions of the two units and to prevent the operator from manipulating the maintenance panel should he be unqualified to do so.

MAINTENANCE

The RW-300 has been designed for ease of maintenance. Built-in test equipment is provided so that maintenance can be performed without additional equipment. This includes an oscilloscope that can be connected to any one of the five registers, the clock signals, the output of the read amplifier, etc. A bank of six neon lights which can be connected by appropriate setting of a switch to look at the states of various flip-flops is provided.

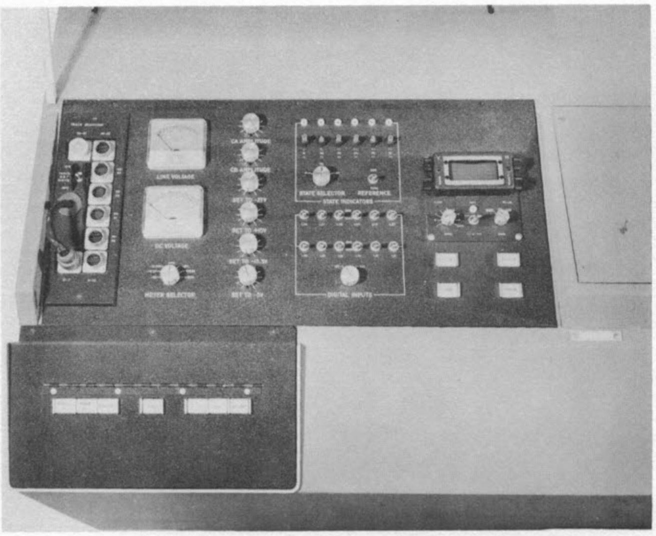


Figure A-6. Operator's panel of RW-300.

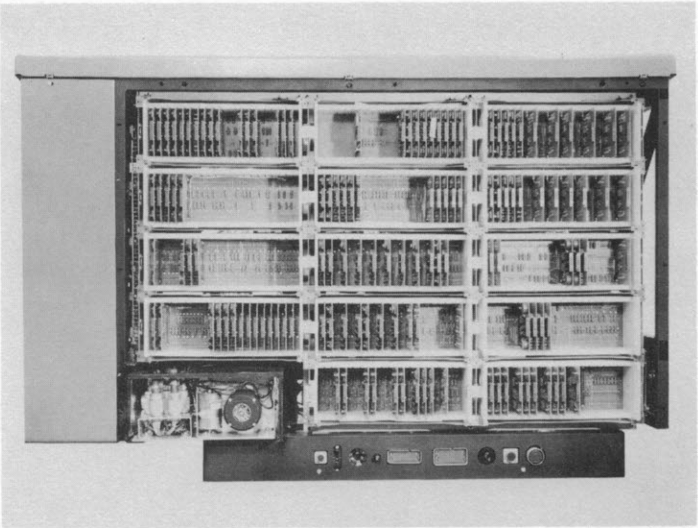


Figure A-7. Rear view of RW-300.

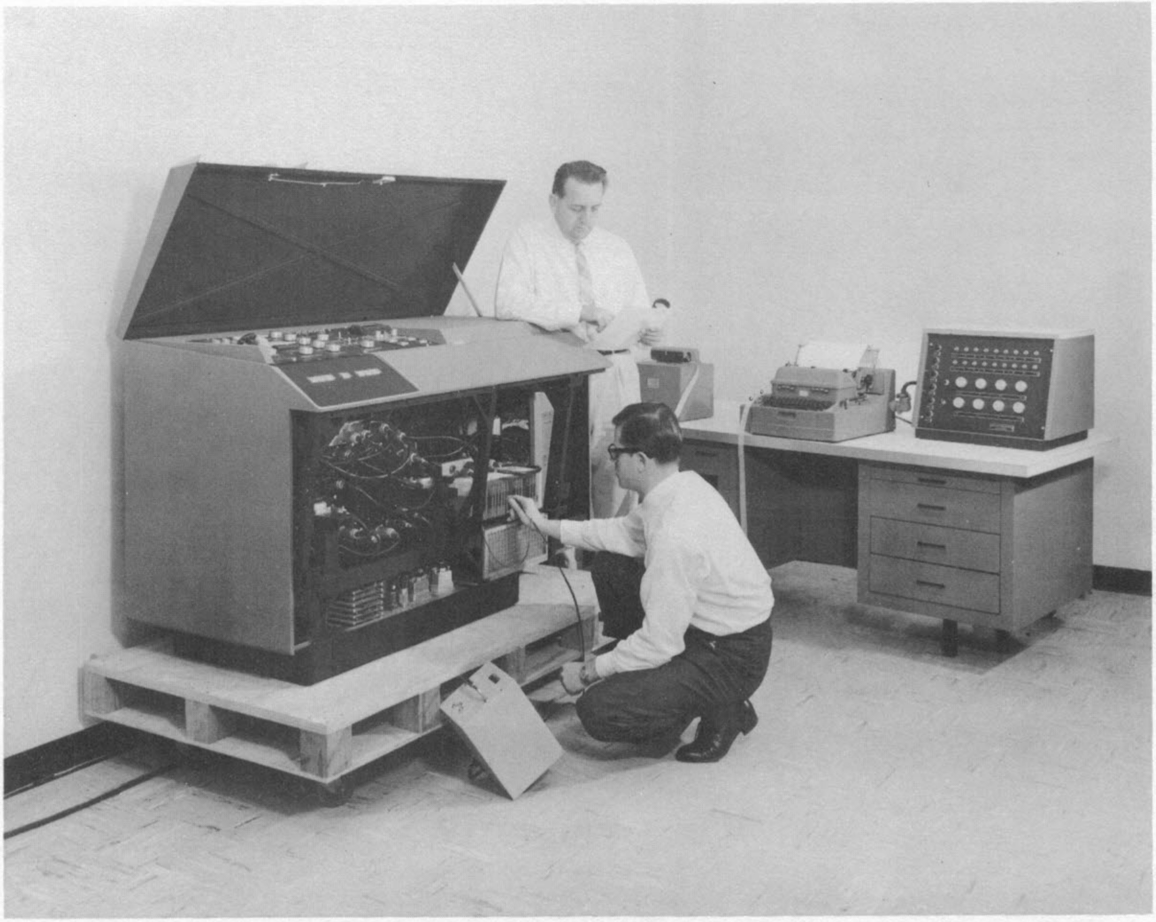


Figure A-8. Front view, showing access to drum and modules.

Another test feature is a provision for sequencing the machine through "half" an operation at a time; thus the machine can be directed to read an instruction from storage and then wait until the maintenance operator causes the operation to take place by pushing a button. Using this feature and the oscilloscope to inspect the registers, the operator can follow the execution of any portion of a program step by step.

Maintenance of the RW-300 is carried out with the aid of diagnostic routines. These are a set of programs which thoroughly check the operation of the machine and are constructed so that, with the aid of the built-in test equipment, faults can be quickly detected and pinpointed to a particular insert or module.

Preventive maintenance by marginal checking is provided. Operating voltages can be varied and test routines used to detect weak components. Voltmeters are provided to measure the power supply outputs.

The packaging approach of the RW-300 makes the correction of a fault easy. Insert boards and modules can be easily removed and replaced. Test points for each circuit are provided which permit the detailed inspection of that circuit without removal of the insert card or module from the machine. The magnetic drum can be quickly unplugged and removed. Easy access to all modules is provided (Figure A-8).

ENVIRONMENT

The RW-300 has been designed to operate in any normal industrial or laboratory environment. Special features of the RW-300 with regard to its operation in this environment are:

1. All contacts other than those used during maintenance are hermetically sealed in accordance with the provisions of the National Electric Code for Class I, Division 2, Group D.

2. Typewriters with hermetically sealed contacts are available.

3. An air purgeable upright model RW-300 is available.

4. Specially treated circuit elements may be provided which will be insensitive to corrosive atmospheres.

INSTALLATION

Essentially no special installation expense is required. The RW-300 operates from 110 volt 60 cycle a. c. power. Only around 500 watts are used. The small size and light weight of the RW-300 ensures that it can be operated in most ordinary rooms, and can be easily relocated at a later time if required.

Connection to test or process instruments and controllers is performed by our trained installation crews.

SUMMATION

The following features of the RW-300 are especially noted:

Control Capability

The RW-300 can not only process and log data, but also control parameters in a test or process as a result of decisions made during the test or process.

Flexibility

The actions taken by the RW-300 are determined by a stored program digital computer. Its repertoire of instructions and storage capacity are such that it can perform the control calculations for complex processes. Future changes in the process can be assimulated by the computer simply by modifying the instructions in its program.

In addition, the computer can be used for general purpose computation. In this application the RW-300 compares favorably in speed and capacity with any general purpose computer in its price class.

Compatibility

The RW-300 incorporates integral input-output, buffering, and analog-digital conversion equipment, so that the computer can be connected directly to process instruments and control devices.

Reliability

The RW-300 is designed for long, continuous, trouble-free, dependable service under the exacting and often rigorous conditions which prevail in test stand installations and industrial plants.

Compactness

Miniaturized, the RW-300 is small in size and light in weight; yet it provides the capabilities usually found in larger, more expensive computers.

Maintainability

Test instrumentation is built into the computer to expedite trouble shooting. Transistorized printed circuitry and modular construction facilitate rapid, convenient servicing. Ordinarily, test operation need not be interrupted during maintenance.

RELIABILITY OF THE RW-300

RELIABILITY DESIGN CONSIDERATIONS

Digital control systems for industrial processes, test stand operation, and other real time applications require a substantially higher degree of reliability than that required of computers for engineering computations or business data processing. Operating time percentages of 85 percent to 95 percent, which are the actual performance of most commercial data processing equipment, are not adequate for real time systems.

Operating time percentages, however, can be misleading. We believe that mean time between failure is a more meaningful representation of computer reliability. The reliability design objective of the RW-300 computer system was a mean time between failures of 500 hours. As a result of the exhaustive test routines conducted, which represent thousands of hours of computer operation, a performance record of better than 1500 hours between failures has been achieved.

Because of this need for unusual reliability, one of the first steps in the development of the RW-300 was to conduct thorough analyses of the factors which affect system reliability. These analyses included the following:

(1) Assessing the realizable operating lives of the best available electronic components.
(2) Determining the causes of component failures.
(3) Discovering the statistical relationship between basic component and complex system reliability.
(4) Determining the effect of time and environment upon component characteristics.

As a result of their studies, Ramo-Wooldridge engineers were able to proceed along several lines to ensure users of RW-300 control systems the minimum possible amount of downtime:

(1) Only components which had conclusively demonstrated the highest reliability standards were incorporated into the design of the RW-300.

(2) Circuits were designed expressly to be insensitive to variations in component characteristics.

(3) New techniques were developed to facilitate rapid maintenance.

This Appendix discusses how these studies were conducted and applied to the design and construction of the RW-300, and indicates their significance in the resultant reliability of the equipment.

SYSTEM RELIABILITY

Reliability of operation of complex equipment is obtained only by the careful and thorough attention of the designer and producer of the equipment to the details of the equipment and the environment in which it will operate. Automatic logging, scanning, and computing equipment is a complex piece of electronic apparatus composed of thousands of electronic components. Each of these components has a probability of failure. Although this probability of failure for an individual component may be very small, the probability of failure of a system composed of thousands of these components is a statistical combination of the probability of failure of these individual components. Only when particular care is taken will this system probability of failure be small enough so that many hundreds of hours of operation without failure can be obtained.

In the design of the RW-300, a study was made of the reliability obtainable using available electronic components. In this study, records of equipment used by the military services and records of the failure of components in scientific computers and business data processing machines were analyzed. A set of design standards for the components used in the RW-300 was set up so that the resultant probability for failure of the system as a whole would be less than one failure per thousand hours of operation.

Since the probability of failure of the system is so strongly dependent on the number of components in the equipment, an important factor is the minimization of the number of components required to perform a particular function. In the design of digital computers, there are many different ways to organize the components into an arrangement which will perform the same computing functions. Some computers which perform essentially the same computing tasks have differences in component counts of more than a factor of two. In the design of the RW-300 equipment, highly developed mathematical techniques of logical design were applied which have been very effective in minimizing the number of components. The extent to which this has been achieved is indicated by the fact that there are only 460 transistors in the computer proper.

COMPONENT RELIABILITY

Each component selected for use in the RW-300 was required to pass special qualification tests. These tests were designed to indicate such things as variations in the manufactured lots and the response of the component to environmental disturbances such as temperature changes, mechanical vibration and shock, humidity, and corrosive atmospheres.

The semiconductor components used in the RW-300 are hermetically sealed, and have been used extensively in other types of electronic equipment where they have an exceptional reliability record.

High quality standards were also maintained in selecting resistors and capacitors for the RW-300. One percent boron carbon resistors were chosen for most circuits, as offering greater moisture resistance and better accuracy than the five percent carbon type commonly employed in digital computers. Similarly, glass capacitors were used instead of mica capacitors in nearly all places.

In the analysis of component behavior and selection of the type of approved components, the variations of the component characteristics with time and the effect of this on circuit tolerances were considered. The component variations considered in the circuit design were those relating to the end-of-life tolerances of the components.

CIRCUIT TECHNIQUES

The circuit techniques used in the RW-300 are the most reliable known. They are circuits that will continue to operate properly when the components, supply voltages, and input signals have varied significantly from their design values.

Automatic logging, scanning, and computing equipment is composed largely of circuits called switching circuits. A carefuly study was made of the various techniques of switching circuits. Among those studied and rejected were magnetic switching circuits and direct coupled transistor logic circuits. This latter technique has become somewhat popular because the elementary switching circuit in it has very few components, and attempts are being made to apply it in several computers now being developed. However, all the computers that have been built using this circuit technique have been sensitive to environmental conditions, particularly noise and temperature variations. Our analysis of this circuit technique is that considerable complication of the basic circuit would be required in order to remove this sensitivity to environmental conditions.

The basic switching network of the RW-300 is an R-W designed transistorized dynamic flip-flop which drives a network of diodes. This type of circuit technique reduces to a minimum the number of transistors required to perform the switching function. In addition, it leads to increased reliability because unlike static flip-flops, RW-300 flip-flops change voltage state with every clock pulse.

In the evaluation of circuit designs for the RW-300, specifications on the margin of failure were set up. These specifications were determined on the basis of the reduction in margins caused by initial, end-of-life, and temperature variations of the component characteristics. All of the circuits were designed to operate over power supply variations of a minimum of $\pm$ 10 percent of the design value, and the circuits were required to operate with component characteristic variations of at least $\pm$20 percent. Circuit designs and their test results were reviewed before approval to insure that they met the requirements on tolerance characteristics, marginal check, functional and environmental capability, and component specifications. In acceptance tests, all circuits were environmentally tested over a temperature range of 0°C. to $+55^{\circ}$ Centigrade.

In the analog input-output unit, some of the switching is performed by relays. The relays finally accepted for use are hermetically sealed, mercury-wetted contact relays, which have a life expectancy of over 100 years at the usage rate required in typical RW-300 installations.

STORAGE TECHNIQUES

A particularly vital part of any digital computer is its storage device. It is especially important in process control applications, since the functions of the equipment are determined by a program stored in this device.

Many different types of storage techniques have been used in digital computers. Experience has narrowed down the techniques which are in use today in on-line applications to essentially two -- magnetic drums and magnetic cores. A careful investigation was made of both of these techniques to determine the one best suited for a process control computer. In both of these storage techniques, information is stored in terms of the magnetic state of a small piece of permanent magnetic material. In magnetic drum storage, this piece of magnetic material is a small region on the surface of the drum; in magnetic core storage, it is a tiny doughnut-shaped magnetic core. Both of these types of storage are intrinsically very reliable in the sense that the magnetic state of this material is unlikely to be disturbed by reasonable environmental influences. Some important differences between these two techniques appear when one considers the peripheral equipment required for reading, writing, and selection of information. The magnetic drum was chosen as the principal storage for the RW-300 Digital Control Computer for the following reasons:

(1) The most important reason for selecting the magnetic drum is that reading information from the drum does not alter the stored information. In contrast, the readout of a core memory is destructive; each time information is used, it must be rewritten into the core storage if it is to be used again. In process control, the program which determines how the equipment is used is stored in the storage unit. If magnetic core storage is used, there is a possibility that an instruction may be altered as it passes through the regeneration circuits resulting in a permanent error. This type of error cannot occur in the magnetic storage of the RW-300, since the program is recorded on a section of the drum which is unalterable during programmed operation. Thus, after the initial recording, it is practically impossible to create an error in the program recorded in the RW-300 without physically damaging the storage unit.

(2) In the present state of development, magnetic core devices operate satisfactorily only when kept in a temperature range of the order of $\pm 10^\circ$ Centigrade. This would require that the room in which the computer is operated have its temperature rather carefully controlled. With the magnetic drum, close temperature control is not necessary. The magnetic drum storage used in the RW-300 will operate reliably over a temperature variation of more than $\pm 50^\circ$ Centigrade.

(3) The circuitry for selecting a particular part of the storage is more complex for magnetic cores than for magnetic drums. With the magnetic drum, part of the selection is performed by the rotation of the drum.

The occasionally mentioned advantage of magnetic cores over magnetic drums that they have no moving parts is really not of much significance in the ultimate reliability of the equipment. The moving part of magnetic drums is a uniformly rotating cylinder which in the RW-300 rotates at the comparatively low speed of 3600 revolutions per minute. At this speed, rotating machinery normally has a life of many years. None of the magnetic drums built at Ramo-Wooldridge has ever had a mechanical failure. One reason for this may be found in the centrifugal pumping action of the drum which ensures temperature equilibrium throughout the drum housing. This design is a unique feature of the RW-300 drum.

The use of a magnetic drum storage, and the circuit techniques chosen for the RW-300, would permit reliable operation at clock frequencies well in excess of 250 kilocycles. However, in keeping with the conservative design philosophy of the RW-300, the clock frequency was chosen to be 150 kc to provide a substantial margin for all circuits. In addition, to eliminate any possible "noise" effects in communications with the drum, the write amplifiers have been mounted directly adjacent to the recording heads.

PACKAGING TECHNIQUES

The mechanical structure of electronic equipment is very important to its reliable operation. The techniques of mounting, wiring, and packaging circuit components in the RW-300 represent an advance over those used in previous electronic equipment. All transistors are clip-mounted. All active circuits are mounted on printed circuit insert cards. These cards are plugged into modules in which the diode networks are also mounted with printed circuit techniques. Through extensive use of printed circuit techniques, hand wiring has been kept to a minimum.

Connectors for plug-in units are of the gold-plated, beryllium copper, interference type. They have been subjected to insertion test running well above 10,000 insertions and operated satisfactorily, maintaining proper insertion force and low contact resistance. Wiring to the connectors is accomplished by taper-pin techniques, with stranded wire employed throughout to minimize the chance of breakage. The cable connectors are of the standard AN types with a quick disconnect feature.

CONTROL OF QUALITY

The design standards described in the preceding paragraphs are very important to the development of reliable equipment. Of equal importance are the methods used to insure the maintenance of this quality in the manufactured product. Quality control procedures set up for manufacture of the RW-300 involve the incoming inspection of purchased parts and materials, rating of the vendors supplying the materials, inspection of purchased parts and materials, rating of the vendors supplying the materials, inspection of fabrication procedures and processes, inspection and testing of subassemblies, and testing of the complete system. The high reliability required of process control systems requires more than the normal inspection standards used in the manufacture of commercial equipment. A system of follow-up of failures detected in the inspection and testing has been developed to insure continued quality in manufacture.

The standards adopted in the design and manufacture of the RW-300 have meant that the cost of components and assembled system is somewhat higher than if standard commercial practices were used. These standards were adopted because it was believed that they will produce an advantage to the customer in terms of increased operating times without failure that will in the long run more than offset the higher price.

These considerations of design and manufacture can, of course, only tell part of the story. The real test of the reliability of the RW-300 is in operation at the customer's plant.

The prototype model of the RW-300 has now been in continuous operation for over 2-1/2 years in our Los Angeles laboratories. Its performance in exhaustive test routines has confirmed the successful application of the high reliability standards previously mentioned. First models of complex systems usually have very many troubles; the prototype RW-300, however, has had few operational difficulties. The failures which have occurred, moreover, have resulted in slight design modifications, with the result that the later production-model machines have achieved an even higher level of reliability. At the present time, over five years of total operating time have been logged on these RW-300's, in tests and in actual installations.

DESIGN FOR MAINTAINABILITY

The design and production standards for the RW-300 described in the preceding paragraphs will make it very reliable. However, like every other piece of equipment, it may be expected to fail occasionally. Therefore, a very important aspect of reliability is the ease and speed with which failures can be detected and diagnosed and the equipment again made operational.

The RW-300 was designed to make its maintenance much easier than that of previously available equipment. All active circuits are mounted on etched board plug-in units. These boards are plugged into modules on which the diode networks are mounted and the interconnecting wiring etched. These modules in turn plug into the equipment frame.

Test equipment for detecting and locating faults is an integral part of RW-300 equipment. This test equipment used with specially prepared diagnostic test programs permits the speedy location of a fault to a module and then to the circuit board in the module. The faulty circuit is then replaced and the equipment put back in operation.

Component failures can be of two types -- out-of-tolerance failures and catastrophic failures. The first is a slow change in a characteristic of the component while the second is one in which the component ceases to function. Out-of-tolerance failures, in general, cause intermittent failures of operation of the equipment, whereas catastrophic failures cause permanent (until the component is replaced) failure of operation.

The RW-300 built-in test equipment provides marginal checking facilities to detect out-of-tolerance components before they have produced an operational failure. In marginal checking, certain voltages are varied so that the circuits become more sensitive to component variation. This forces the out-of-tolerance component to cause an operational failure which the diagnostic test routine can detect and locate. Many out-of-tolerance failures can be detected, by periodic marginal checking, before an operational failure has occurred.