# A Coordinated Data-Processing System and Analog Computer to Determine Refinery-Process Operating Guides

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## General Description of the System

THE coordinated data logging and computer equipment, which has been constructed for Esso Standard Oil's Belot Refinery, Havana, Cuba, measures and records the true value of 101 process variables and 11 operating guides. The measured variables are gas flows, liquid flows, level, pressure, oxygen percentage, and temperature. The inputs to the logger representing flows, level, and pressure are in the nature of 3 to 15 psig signals. The oxygen percentages and temperature signals exist as dc mv signals. Unique in the system is the incorporation of an analog computer which calculates 11 operating guides. These are computed at the end of a readout cycle from the logger. The operating guides computed are the following:

1) Carbon burning rate,
2) Catalyst-circulation rate,
3) Catalyst-to-oil ratio,
4) Ratio of feed-to-reactor catalyst hold-up,
5) 430° FVT conversion-corrected,
6) Percentage weight of hydrogen in coke,
7) Per cent weight of carbon make on total feed,
8) Heat duty of top pump-around system,
9) Heat duty of mid pump-around system,
10) Regenerator superficial velocity,
11) Reactor superficial velocity.

The logger can be adjusted to give a complete readout of all process variables every 10 minutes, 30 minutes, or hourly. At the end of the hourly logging cycle, information required by the computer is fed into the computation circuits which proceed to calculate the 11 operating guides noted above. As the computation for each guide is completed, the true value is logged on the output typewriter. Thus, a given set of guides is based on information given in the logging cycle immediately preceding the computation period. Scheduled logging is supplemented by "on demand" logging and can be initiated at any time by the operation of a push button.

Two electrically actuated automatic typewriters with separate tape punch have been furnished to record the outputs of the automatic logger and analog computer. The tape punch produces a 5-channel punched-tape output suitable for the actuation of IBM equipment. In order to provide for proper utilization of this tape, the following information accompanies the data:

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1) A symbol to identify "on demand" readouts.
2) Tabulating card-advance and card-eject signals for each group of 15 data points.
3) Tabulating card number for each 15 data points.
4) Time to the nearest minute for each tabulated card.
5) Unit-identification number for each tabulated card.
6) An identification character on each card in order to differentiate preset hourly readings which are of interest to accounting and other groups for manual or more frequent readouts demanded by the operator but not essential to tabulating card computations.
7) Two additional identification characters on each card in order to identify ultimate data users.

The equipment is housed in two cabinets in the following manner. One cabinet contains the transducing equipment for the process variables, and the programming equipment for the data logger; the second cabinet houses the computing circuits. Both cabinets are arranged to permit a continuous air purge. In addition, the computer cabinet was provided with an air-conditioning system in order to dissipate the electrical heat generated by the computing elements. All equipment has been designd to conform with specifications for a Class I, Group D, Division 2 area as defined in article 500 of the 1953 National Electrical Code.

It should be noted that among the process variables being logged are three gas flows which have been pressure and temperature compensated. All flows are printed as hourly averages and 24-hour totals. Five of the temperatures are printed as hourly arithmetic averages, and 61 are printed as instantaneous values. All necessary linearization of thermocouple inputs, the conversion of customers 3-15 psig pneumatic signals to digital signals, and the extraction of square-root functions have been provided in order to check the over-all accuracy of the automatic logger. These points are printed out on the log sheet before each readout cycle. A dead weight loaded precision pneumatic comparator has been provided to check the pneumatic-to-digital transducer which is used for the pneumatic-signal inputs.

The accuracy for the logged-process variables is as follows:

1) Temperature $\pm$ 0.25 per cent.
2) Pressure $\pm$ 0.5 per cent.
3) Compensated flows $\pm$ 1.0 per cent.
4) Integrated and averaged flows $\pm$ 1.5 per cent from 10 to 25 per cent of full-scale flow, $\pm$ 0.75 per cent

from 25 to 50 per cent of full-scale flow, and ± 0.5 per cent from 50 to 100 per cent of full-scale flow.

The accuracy of computation for the operating guides is ± 2 per cent.

## Use of AC Computer Signals

Because the computer must be capable of operating at a 100 per cent duty cycle, that is to say, 24 hours per day for 365 days per year, the signals handled by the computing circuits are in the nature of 60-cycle ac voltages. This was done in order to produce a high degree of reliability in the equipment. Most conventional computers today utilize signals which are dc voltages. In order to obtain the best possible degree of accuracy and minimum drift, it is necessary that all dc signal voltages be checked for proper calibration before the problem is solved. This becomes a frequent maintenance procedure in the case of a continuously-operated piece of equipment. In order to eliminate the need for a periodic check of all signal-voltage accuracies and amplifier balance, the signal voltages in the computer are obtained from a group of transformers. These have been designed to operate on a primary voltage of 220 volts, 60 cycles. In practice, the transformers are operated on 115 volts, 60 cycles. We have therefore supplied twice as much iron in the laminations as actually required. This insures that the transformers operate on the linear portion of their magnetic-characteristic curves. This is done so that we are certain that the coupling flux within the core does not approach the saturation level and that the secondary voltages contain a minimum of distortion and bear a constant proportionality to the primary voltage. The transformers are wound with a turns-ratio accuracy of ± 1 per cent. The signal voltages are then padded to the desired accuracy by means of adjustable rheostats connected in the secondary circuits. In order to further insure repeatability between the units handling a multiplicity of signals, all transformers are loaded equally. Furthermore, they were constructed with laminations stamped from a uniform batch of iron in order to further insure repeatability among units. The result is a signal-source module of five volts, 60 cycles. When signals of greater magnitude are required, additional transformers are used with their primaries connected in parallel, and their secondaries connected in series.

For example, if a signal of, say, 22.00 volts were required, we would supply five transformers with their primaries in parallel, and their secondaries in series. This, it can be seen, results in a "voltage stick" which is 25 volts long. We take the signal from the low end of the voltage stick to a point 22 volts from the end.

This reasoning was applied since a computer operating with signals which were obtained as described above will require no standardization or reference to a secondary voltage standard, nor will it require any special regulation of line voltages. It is felt that this results in a more reliable system of equipment, and restricts computer down-time to a program of preventive routine maintenance.

## Types of Computer Inputs

The information fed into the computer is derived from several sources as follows:

1) Logged during a readout cycle and stored as a shaft position prior to the start of the computation period,
2) Derived during the computation period and stored as a subroutine for use later in the computing cycle,
3) Fed into the computer manually.

Fig. 1 shows a representative segment of an information time-flow diagram. As can be seen, the computer solves the 11 equations in sequence, beginning with (1) and proceeding to (2), (3), etc. In order to solve a particular relationship, it is necessary to obtain the values for all variables involved in the equation. As the diagram indicates, these may consist of parameters which have been logged during the previous readout cycle, variables which have been manually set, or those which have been stored as a subroutine during a previous computation. When all of the necessary data have been assembled, the information is fed into the computer, and when the output device has come to balance, the desired solution is printed out on the logger typewriter. The computer programming circuits then proceed to assemble the data necessary to solve the next equation.

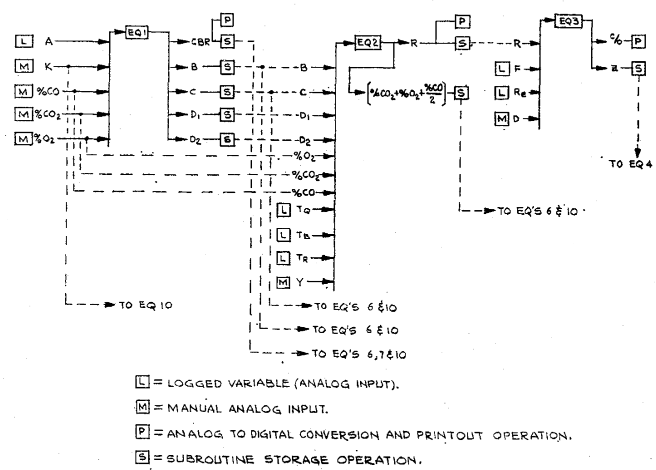


Fig. 1—Information time flow diagram.

When this information is available, it is fed into the computer circuits which proceed to solve the next relationship, etc. When the last operating guide, or (11), has been solved and typed out, the computer circuits are disengaged from the logger for a period of one hour at which time the next computation period is initiated.

## A Time-Shared General-Purpose Computer

In order to perform the necessary computation with a minimum of equipment, it was decided to assemble a group of computing elements consisting of algebraic summation elements, coefficient modules, and electronic multiplication or division elements, and to program their input and output circuits to solve for the value of each operating guide serially. This means that a given computer building block may be used repeatedly with a minimum duplication of equipment. This time sharing of computer "elements" makes it possible to assemble a so-called general purpose computer and, in effect, makes it a specific purpose machine through programming. To determine the actual number of computing blocks required, a study of the relationships to be calculated was made, and a block diagram for each relationship was established. The equation requiring the greatest number of elements then determined the diversification and number of modules to be included in the computer. Since all other relationships are of a simpler nature, we use the building blocks over and over again to solve these less complicated equations.

Fig. 2 shows a typical computer block diagram. The relationship to be solved, in this case reactor superficial velocity, is shown at the top of figure. The input-signal information is shown at the left-hand side of the figure. The block diagram indicates how the various signals are modified and combined in order to solve the desired equation.

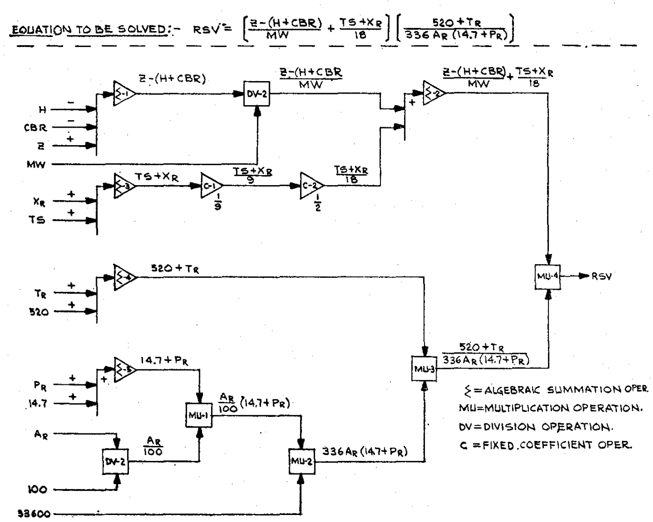


Fig. 2—Typical computer block diagram.

The references shown in the diagram refer to the analog signals as ac voltages with respect to ground, that exist at the various points in the circuit. The equation is generated, so to speak, by starting with single terms which are combined by addition, subtraction, multiplication, and division until the desired results are achieved at the output (shown at the right-hand side of the figure). It was necessary that we know the variation in magnitude for each of the individual input signals so that we could assign appropriate signal voltages to these inputs during the process of scaling the computer parameters.

## Types of Computer Building Blocks

In order to time share the various computer elements, it was necessary to switch a given module between the several circuits in which it was to be used. To illustrate how this was achieved, diagrams are included showing how the computer relay programming is used to accomplish this switching.

Fig. 3 shows the circuits for a typical time-shared summation amplifier. In this case, we desire first of all to add voltage E1 to E3 in one equation and then, at some later time, to add voltage E2 to E4. It will be noted that the input signals are connected to the amplifier by means of computer programming relays with contacts R1 and R2 as shown. The signals are switched by Form D (or make before break) contacts which insure that the input to the amplifier is not open-circuited during the switching operation. The stage gain of this particular type of amplifier is made equal to unity by suitable adjustment of the feedback resistor $R_F$ and the input resistances $R_{I-1}$ and $R_{I-2}$. Furthermore, it can be seen that, to minimize any dc drift within the amplifier itself, a chopper-stabilizer module has been included. Should it become desirable to check the dc output level as referred to the input, a test switch has been provided as shown. This switch decouples the amplifier from any existing input signals and returns the summing junction to ground through a suitable resistance. A dc volt meter can then be placed from the output of the amplifier to ground, and potentiometer RA manually adjusted to reduce the dc unbalance to zero.

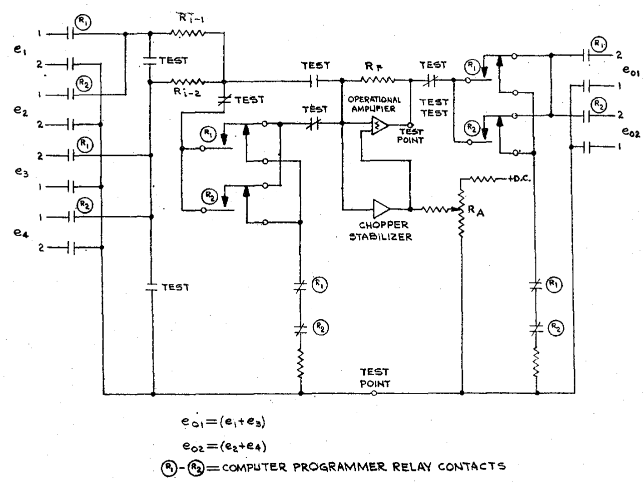


Fig. 3—Summation amplifier.

Fig. 4 illustrates how these same principles are applied to an operational amplifier being used as a coefficient module. That is to say that the input voltage is multiplied by a fixed constant depending upon the position of the sliding contact on a multiturn potentiometer associated with the desired constant. Here again, it will be noted that the switching operation is accomplished by Form D contacts (or make before break) so that neither the amplifier-feedback loop nor the input-summing junction is left open-circuited during the switching operation.

The chopper-stabilizing amplifier is again included, as well as the test switch, should it be desirable to check the dc level of the output with respect to the input.

Further reference to the diagram will show that the polarity of the input signal determines the alegbraic sign of the term it represents. Thus, if we desire to add two signals together, we arrange to feed voltages of like polarity into the summing amplifier. If we desire to take the difference between two voltages, the signals are fed 180 degrees out of phase. This simply means that the secondary leads from the signal transformer are reversed, resulting in the necessary phase reversal. It should also be noted that the operational amplifiers used invert the signals fed to their inputs; that is to say, if a signal with polarity 1-2 is fed into an amplifier, the output voltage will have phase 2-1. It was therefore necessary to study the relationship being solved in order to determine the phase relationships between the various input signals.

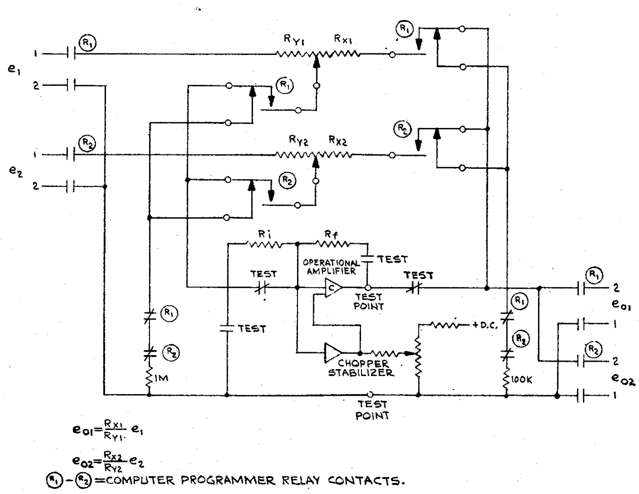


Fig. 4—Coefficient amplifier.

Fig. 5 illustrates the method of handling an electronic multiplier-divider element using ac analog signals. Since the device is a true multiplier, it was necessary to avoid the sine-squared relationship which results when two ac signals are fed to the inputs of the module. It will be seen that one signal is converted to a dc voltage by means of a full-wave rectifier and forms the input applied to terminal No. 2. This voltage is then modulated by the signal applied to input No. 1. The output signal is proportional to the rms product of the input signals in the case of multiplication, and to the ratio of the rms amplitudes of the inputs in the case of division. Contacts on the computer programmer relays determine whether the block will be used for multiplication or division. Auxiliary operational amplifiers $C_D$ and $C_M$ were provided in order to give the proper output voltage relationships. All amplifiers within the multiplier-divider were chopper stabilized in order to minimize any dc drift within the element itself. The circuit shown was arranged to provide a multiplication and division element with unity gain. In order to increase reliability and minimize drift, it should be noted that all computer building blocks were provided with chopper stabilization and also

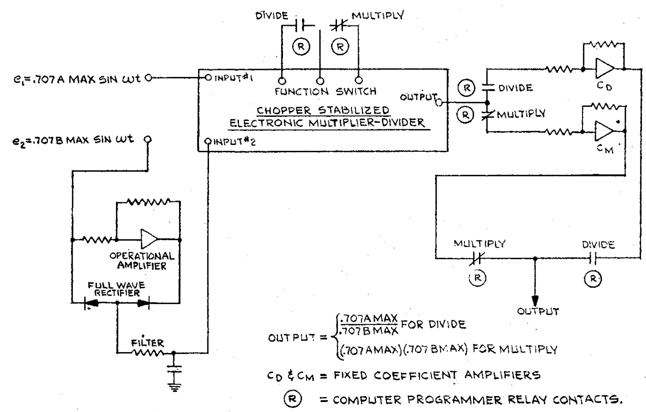


Fig. 5—Multiplication and division circuit.

means for manually adjusting any dc unbalance which may occur in operation.

## Memory Systems

Information stored in the computer is derived from 3 sources:

1) Information stored as a shaft position within the logger itself.
2) Data which exist within the logger instantaneously during a readout cycle, but which must be maintained for use as a computer signal.
3) Information stored as a subroutine during the computation period.

Process variables which are read as integrated quantities such as compensated flows and hourly average temperatures exist as shaft positions in the logger. Fig. 6 shows the circuit for a typical compensated gas flow. In this arrangement the position of the contact on the accumulator slide wire is a function of the flow which has been pressure and temperature compensated. During the logging cycle, the flow accumulator slide wire is connected to the logger readout device. During the computation cycle, however, an ac voltage from a computer signal transformer is impressed across the terminals of the slide wire, and the voltage developed from the contact to the low end of the slide wire is returned to the computer as an ac signal for use in the computation circuits. It can thus be seen that the accumulator slide wire is time shared between the logger circuits and the computer circuits. Moreover, there are computer parameters which are derived from signals that exist in the logger only instantaneously as the logger programmer scans the customer input information. For example, instantaneous temperatures, as given by thermocouples, must be stored at the time that they are read during the logging cycle and must be maintained in memory in a form which can be used by the computer. This was accomplished by means of a small electromechanical servosystem. The input signal from the thermocouple is fed to the logger readout device. A retransmitting or follower potentiometer mounted on the shaft of the logger readout device transmits a dc voltage to a storage servosystem located in the computer cabinet. The shaft of this servo then

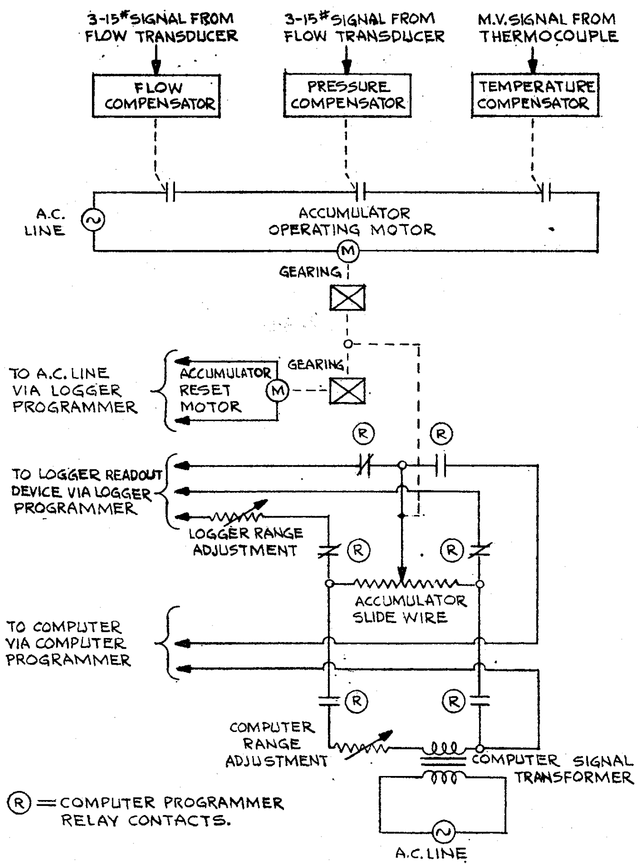


Fig. 6—Typical compensated-flow circuit.

assumes a position proportional to the value of the input temperature being measured. A follower potentiometer mounted on the shaft of the storage servo is then used as a computer input information by impressing across its terminals an ac voltage from a computer signal transformer.

Subroutine storage within the computer itself is achieved in a similar manner. The ac voltage representing the quantity to be stored is fed to a storage servo whose shaft again assumes a position proportional to the stored quantity. Retransmitting or follower potentiometers mounted on the shaft of the storage servo are then used in subsequent computations.

## Signal Sources

The signal-source transformers were treated in a manner similar to that of the computer building blocks themselves. A single transformer is time shared between the circuits comprising several of the relationships to be handled by the computer. Fig. 7 illustrates this point. The diagram shows a single signal-source transformer which has been time shared between four equations. The signal to be used for (1) is generated across potentiometer $P_{1B}$ which is shown as a manually-set variable. The voltage to be fed for (2) is generated across potentiometer $P_{2B}$ in series with rheostat $P_{2C}$. Rheostat $P_{2C}$ has been included in this case to provide zero suppression for the instance where the signal does not go to zero at the minimum range of its variation. For (3), potentiometers $P_{3B}$ and $P_{3C}$ are used in an arrangement similar to that shown for (2). In this case, potentiometer $P_{3B}$ is shown as a retransmitting or follower potentiometer mounted on servostorage mechanism $S_{V1}$. The signal to be used in (4) is generated across $P_{4B}$ which is shown as a potentiometer mounted on one of the compensated flow accumulators.

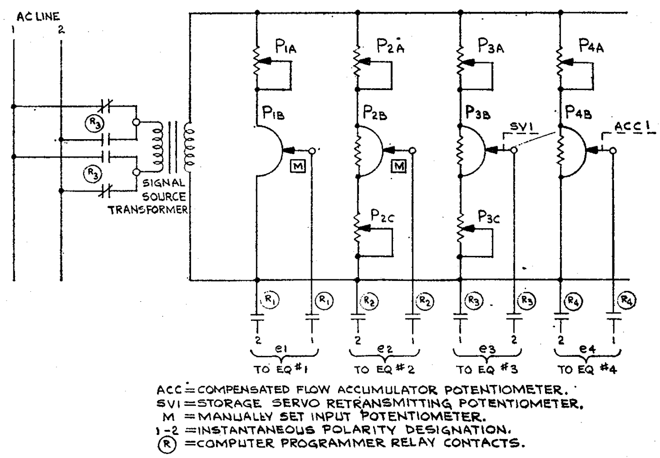


Fig. 7—Representative signal-source diagram.

Potentiometers $P_{1A}$, $P_{2A}$, $P_{3A}$, and $P_{4A}$ have been included as range adjustments set so that the voltage developed across the signal potentiometers is of the correct magnitude, depending upon the scaling desired for a particular variable. Computer programming relays operate contacts R1, R2, R3, and R4 which are associated with equations (1) through (4), respectively. The relay contacts in the primary circuit of the signal-source transformer are used to reverse the phase of the transformer secondary voltage. As mentioned previously, an instantaneous polarity of 1-2 is given the designation of a positive signal in the computer, whereas an instantaneous polarity of 2-1 designates a negative signal in the computer. Reference to the diagram will show that the signals used in (1), (2), and (4) are shown to have a negative sign, while the signal generated for (3) is shown as a positive signal.

In this manner, a single signal-source transformer has been time shared with a corresponding reduction of three in the number of transformers to be supplied. This results in a saving of physical space within the computer cabinet as well as in a reduction in the cost of the necessary components.

## Tie-In Between Computer and Logger

Fig. 8 indicates how the various circuits previously described were arranged to complete the coupling circuits between the automatic data logger and the computer. It should be noted that the addition of the computer in no way affects the operation of the data logger—it was designed to act as a supplementary or auxiliary device.

As previously stated, the logger programmer scans the

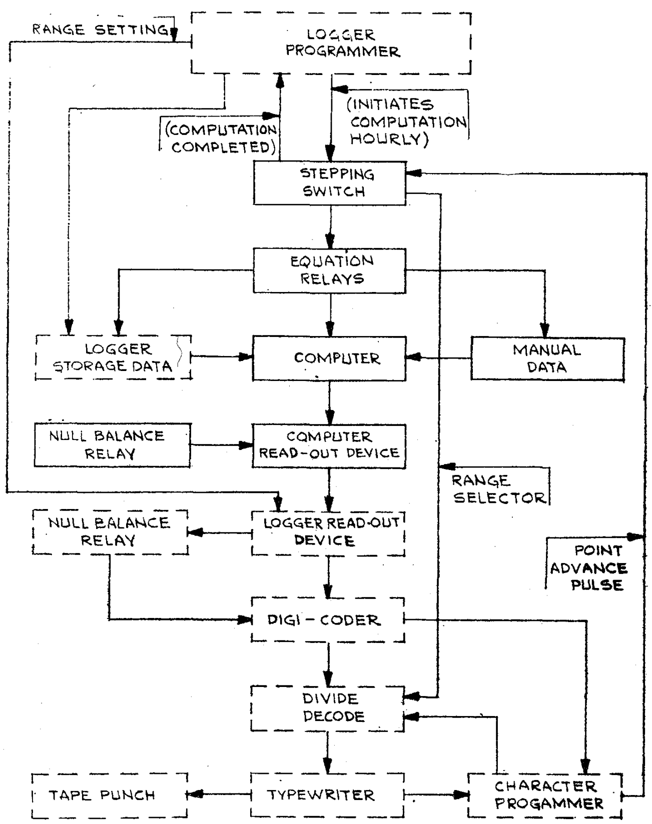


Fig. 8—Coordination between logger and computer.

process analog-input information at least once an hour. At the completion of the hourly logging cycle, the logger programmer sends a signal to a stepping switch located in the computer programmer. This signal advances the stepping switch to position no. 1 and initiates the computation cycle. Position no. 1 on the stepping switch operates a group of equation relays associated with the first relationship to be solved. Contacts on these relays then proceed to select for the computer input information which has been derived from logger storage data as previously described, and manual input data. The equation relays also serve to connect the computer building blocks in the arrangement necessary to solve this first relationship. The output from the computation circuits is fed directly to the computer readout device. This unit is an electromechanical self-balancing ac potentiometer. A retransmitting or follower potentiometer sends a dc signal back to the logger readout device causing the two servos to track. Since the logger readout device is a multirange self-balancing potentiometer, it is necessary that range information be supplied to it from the logger programmer during the computation cycle. A digicoder, coupled through gearing, is used as an analog-to-digital converter which sets up a digital output proportional to a shaft-position input from the logger readout device. The digicoder output is then fed through a divide-and-decode network to the logger typewriter. The characters present in the output are scanned by the character programmer which actually operates the solenoids on the typewriter mechanism. Tape punch information is generated as the typewriter is recording the value of the computer solution.

During the time that the solution to (1) is being typed out, a feedback-point advance pulse is sent back to the stepping switch in the computer programmer which then advances to position no. 2. The equation relays associated with operating guide no. 2 are than energized and the cycle repeats as described above for (1). The programming continues until a solution is obtained for each of the 11 relationships to be computed. At the completion of (11), a feedback pulse is generated by the computer stepping switch and returned to the logger programmer. The stepping switches associated with the logger point programmer then return to the home position where they remain until the initiation of the next logger cycle.