A Digital Computer for Industrial Process Analysis and Control

EDWARD L. BRAUN†

Introduction

AMONG the more important reasons advanced for the relatively unexploited use of digital computers in industrial process control systems are

1) a lack of knowledge concerning process dynamics,
2) inadequate development of computers engineered for and suited to process control applications, and
3) inadequate reliability of current digital computers.

† Genesys Corp., Los Angeles, Calif.

Our purpose here is to describe a computer which has been designed specifically for industrial process control applications. It promises to satisfy reliability requirements, and can be of great utility even in the absence of complete information on the dynamics of a process. This type of machine can be used for either one or both of the following major functions: It can be used to advantage in the quantitative determination of the effects of different controllable parameters on process performance and also as a process optimization control computer.

We shall not consider here the dynamics of a particular process nor attempt to present a quantitative picture of the benefits to be realized from the use of new instrumentation and digital control computers in various industrial processes. These are the subjects of recent and continuing studies by a number of organizations. These studies indicate that the utilization of machines which allow control to be based on process dynamics as well as steady-state considerations may offer, in particular areas, one or more of the following advantages:

1) A reduction in capital investment for new process plants by the substitution of small responsive equipment and control systems for some of the mass and storage capacity on which many plants presently rely for stability and self-regulation
2) A reduction in expenditures for raw materials, heating, cooling, catalysts, etc., as a result of more precise control
3) Improved productivity
4) Improved quality control
5) Realizable, effective control for new processes necessitated by technological progress, and which must function under conditions beyond the present limits of controlled process variables.

Analysis of a Process

The effectiveness of computer control of an industrial process is dependent to a large degree on the data available concerning the effects of controllable parameters on pertinent characteristics of the process. However, this does not necessarily imply that the exact dynamics of a process must be known in precise analytical terms before a process can be controlled. The fact is that control can be and is effected with only a qualitative knowledge of system behavior, coupled with the use of feedback methods.

The objective of a process analysis is the determination of the relationships between the major process parameters and the location of optimal operating regions for the process in terms of these variables. Once the optimum operating regions have been determined, a decision can be made in regard to which variables need be controlled and in what manner in order to maintain optimization of one or more characteristics of the process in the presence of disturbances that may arise.

Let us consider now a relatively simple procedure for analyzing the effects of various parameters on system performance which can be incorporated into the special purpose computer to be described. The procedure consists essentially of specifying initially allowable variations in a number of variables and then programming these changes in order to obtain data on their effects on the various characteristics of the process. The information entered into the computer prior to an investigation consists of the process parameters that are to be varied, the size of the incremental steps of the variation (variable over a limited range), and the upper and lower limits within which the variations must be kept in order to prevent upset of the process. Where two or more parameters are to be varied, the program will cause all combinations of these parameter values (within the imposed limits) to be impressed upon the system. The only other quantity that need be entered is the stabilization time required for the process to stabilize after each programmed change. This delay is usually referred to as dead time or process lag. It allows for the occurrence of two events. First, it permits a process variable to reach the steady-state value called for by a command in the program. Also, it provides time for the over-all process to adjust to this value.

The values of the various quantities whose effects on the process are to be investigated are determined by suitable sensing devices (whose outputs usually are in the form of dc voltages) which are coupled to the computer via an analog-to-digital conversion system. A convenient way of effecting the programmed incremental changes in the process variables is simply to generate commands which cause the set points of the various controllers in the system to be altered. Just prior to the initiation of each new "change" command, the computer causes the current values of all input and output variables of interest to be read out, either in printed form or graphically.

A useful procedure that can be incorporated into the program is to cause a reversal in the sign of the subsequent incremental commands whenever either the upper or lower limits of a particular variable are reached. This produces automatic cycling between preset limits of a given variable. A convenient method of programming changes in a second variable under investigation would be to cause it to be changed by a single increment each time the first variable reached a limit and reversed. A third variable would be advanced by one increment each time the second reversed, and this type of procedure could be used for as large a number of variables as desired.

Specifically, the analysis procedure outlined takes place as follows. First, the variables of interest are programmed for relatively large incremental changes within a limited range around their nominal set points, the latter being determined either theoretically, from simulation experiments, or operator experience. For purposes of visualization, assume that the effects of two input variables upon a particular output variable are being investigated. For each pair of values of the input variables there will be a corresponding value of the output variable. In general there will be a set of values of the input variables which produce the same value for the output and define what may be referred to as process output contour lines. Examination of these contour lines in a particular area will indicate in what direction within the plane to proceed in order to find better values for the output variable. Once the direction has been determined, the computer investigates the new area in like manner. When the new area to be investigated becomes relatively small, *i.e.*, convergence to a solution is approached, the size of the programmed increments may be diminished. Once the optimum setting for a pair of variables has been determined (for fixed values of other process variables), it will be found generally that the effect of a third variable is to cause both a shift and change in size of the optimum output variable contour line. Fig. 1 illustrates the variation in the contour lines of the V_1, V_2 plane as a function of a third variable, V_3. The values associated with each contour line are given by k_i.

The same type of procedure may be used not only in an experimental effort to gain information about a particular process but also in using a computer to control the process. In this case, small adjustments are made in the controlled variables until a set of values is obtained that produces an optimum output. Whenever a deviation from the optimum occurs, the computer initiates a search for a new set of values of the controlled variables that will produce an optimum output. Thus, by experiment and successive approximations, an optimum solution can be produced even in the absence of complete quantitative knowledge of the process dynamics. Useful data are obtained not only on the relationship between specified input and output variables but also on the accuracy of control that would be required for an allowable change in a given output variable.

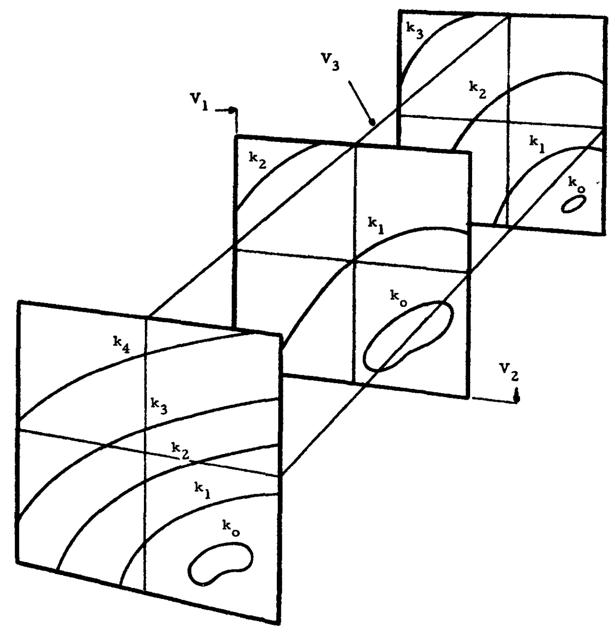

Fig. 1—Planar maps showing the variation of an output variable as a function of three input variables.

Computers for Process Control Applications

For optimal control of an industrial process, it is usually necessary to maintain close control over a large number of process variables in a way which takes into consideration not only the effects of the individual inputs on certain specified outputs but also the relative effects of these input quantities. The control system should have the capacity (in the event that a particular input cannot be made optimum) to generate a compensating change in one or more other variables of the system. Also, it is desirable that the computer be capable of optimizing different process outputs in accordance with the current economics influencing the relative desirability of producing different output products, *i.e.*, the fluctuations of supply and demand.

Once the computer has, by the processes indicated or similar ones, produced data on how a given process may best be controlled, it may subsequently be used to control that process. As a process controller, it is desirable that it have the capability to

1) monitor, store, and log process data,
2) determine the values of the controlled variables that will optimize the output,
3) actuate controllers, and
4) check the system and itself to detect malfunctions in either.

Before proceeding to the description of a digital computer useful for analysis and control of a typical industrial control process like fractionation or distillation, it is desirable to review the general characteristics and capabilities of analog computers and the two major types of digital computers—namely, the arithmetic or integral transfer type of machine and the incremental transfer machine.

The relative merits of analog and digital computers for process control applications have already been considered in the literature. The conclusions reached from these comparisons are that while an analog computer may be adequate in certain cases, it does not in general have adequate capabilities to suit it for more sophisticated control systems. It is limited in its ability to perform operations like the multiplication or division of variables, the generation of functions of several variables, data correlation, extrapolation, etc. It does not have the capacity for logical operations, nor does it provide adequate data storage facilities. It is not well suited for complicated correlation or data processing. Often, it may not be adequate even for relatively simple computations if there are a large number of them, or if nonlinear functions are involved. In addition, a digital machine offers greater flexibility in the sense of relative ease of modification of control functions and also in that it provides a number of facilities in addition to the computations required for control, such as data storage (including the storage of calibration data), logging operations, alarm generation, etc. Finally, the analog computer is more prone to faulty operation from marginally operating components and does not offer the self-checking feature of the digital machine.

The relative merits of integral transfer and incremental transfer machines may be summarized as follows.

The integral transfer machine has excellent data storage and processing facilities with a large measure of operational flexibility. The cost of this is the price of a large main store and a large number of arithmetic and control circuits. The upkeep is also high because the complexity of programming and preventive mainte-

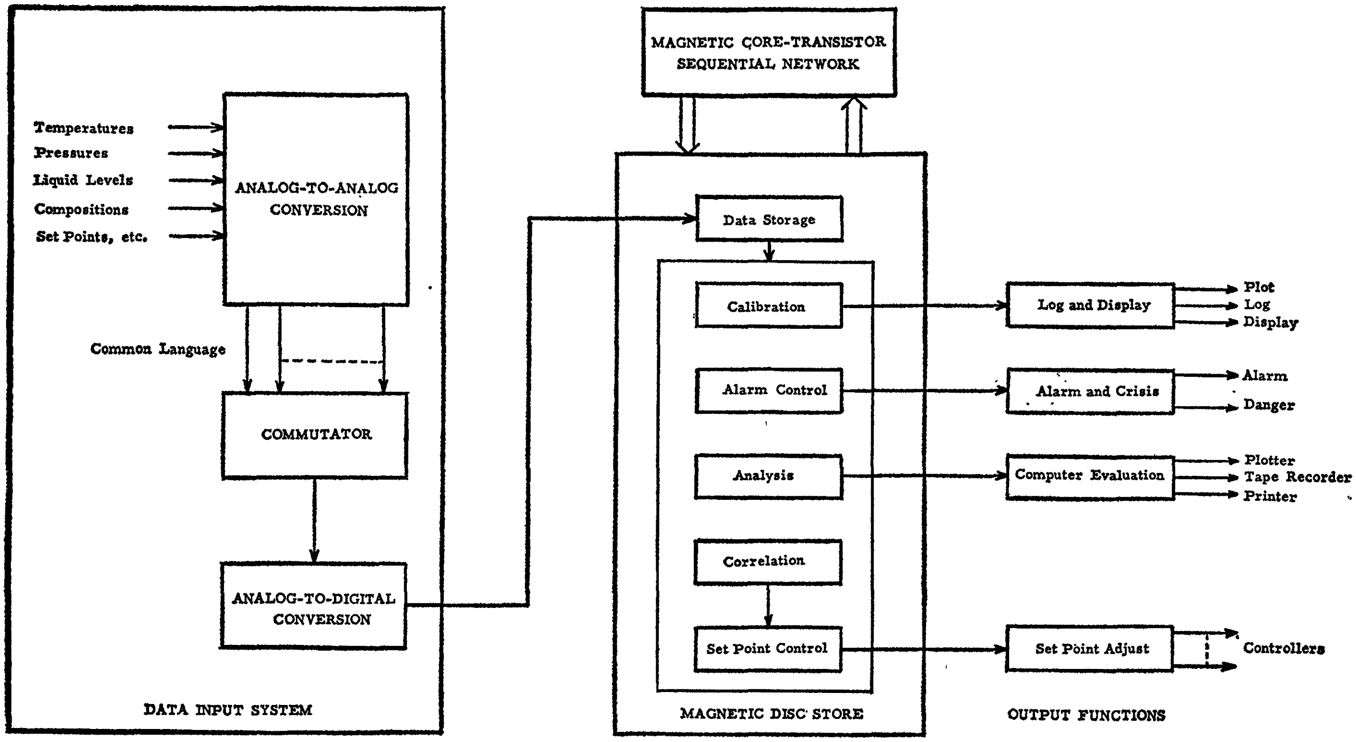

Fig. 2—Functional diagram of industrial process analysis and control computer.

nance procedures demands skilled programming and operating personnel. However, beyond a certain size, additional capabilities and flexibility can be added at little cost. Maintenance of this type of machine is facilitated by its capacity to provide elaborate checks on itself and the control system in which it is incorporated. The integral transfer machine is superior to the incremental machine (even one with variable selectable slewing rates) in slewing time, and therefore better able to implement decisions. However, it is relatively inefficient in computations on continuous variables and capable only of a moderate computation frequency.

Because of its efficiency in computing with continuous variables, an incremental machine with relatively few elements can provide good capacity and a high computation frequency. Its relatively small size gives it considerably better reliability with respect to failures, though its reliability with respect to malfunctions is comparable to that of the integral transfer machine. Also, its maintenance is often complicated because of some of the logical devices used in its design. In its basic form it is relatively poor in respect to slewing time. It is not well suited for problems of logical analysis and is lacking in certain data processing capabilities.

The Industrial Process Analysis and Control Computer

It is apparent that both integral and incremental computation techniques offer advantages. A basic premise of the machine described herein is that it is good economics to minimize the number of active storage and switching elements by the use of incremental computation and stored logic wherever possible. This results in a speed of operation that is relatively slow but adequate for process control applications. A functional diagram of a machine of this type now being built is shown in Fig. 2. As indicated, all the functions of the computer are achieved through extensive use of a magnetic disk store in conjunction with a small magnetic core-transistor sequential network. The functions for which the machine was specifically designed include

1) storage of data from process instruments, instrument calibration data, safe limits of variables, computation constants, etc.,
2) data processing and computational capabilities like integration, function generation, data correlation, smoothing and prediction, solving of differential equations, etc., and
3) generation of signals for adjustment of controllers, generation of alarms, etc.

Briefly, these functions are accomplished as follows.

Storage of the values of all variables for a specified period, say an hour, at a sampling rate of one or two points per minute per variable is accomplished by use of a delay line of several thousand bits capacity. Thus, whenever a variable exceeds prescribed limits, the recent history of the process is available to aid in determining the cause. These data can also aid in operator supervision of the process, since system trends can be checked by read-out of the same variables at different times as a plot.

Analytical or empirical calibration data for selected variables are stored on a group of channels referred to as linearizing channels. To alleviate the problem of instrument drift, measurement by each instrument of a known quantity can be transmitted to the computer at specified intervals. From these data, new calibration constants may be generated and stored as required.

A relatively simple alarm control facility is obtainable by the allocation of certain channels for the storage of upper and lower safe operating limits of certain variables. These data are continuously compared with the data in the long delay line. Exceeding a limit causes annunciators and other alarm indicators to be actuated. Off-limit data can also be logged or plotted whenever alarm conditions are indicated. Computational and logical facilities can be provided to produce anticipatory indications of trouble, *e.g.*, searches can be made for dangerous trends and the simultaneous occurrence of events that imply trouble.

The analyzer is used principally to investigate overall system behavior. It can serve as a simulator, computing the solution to equations describing the behavior of the process and its controllers. It can be used to study the dynamic effects of variations in the choice of controllers, and their set points, utilizing sampled data from the system itself.

The function of the correlator is to aid in the determination of the effects of different controllable parameters on the behavior of the system in order to ascertain what variables to control and to compute optimum set points for their controllers.

Set point control is accomplished with the aid of channels in which the set points and control parameter settings believed desirable are stored. These data are continuously compared with sampled data from the process to determine current settings for the controllers. Also, the settings of the controllers are adjusted to maintain output optimization in accordance with data from the correlator. Any combination of proportional, rate, and integral control can be provided.

A most important requirement of an on-line process controller is a long mean time between failures—of the order of six months. Satisfaction of this requirement too is facilitated by a design that minimizes the number of active storage and switching components. Various devices employed to reduce the component count while at the same time maintaining specified capabilities are

1) simulation of active storage and switching elements by passive storage elements, use of the disk store not only for the function of data storage, but also for arithmetic and logical transformations and control functions;
2) multiplexing of stored information and time sharing of active components,
3) the utilization of both incremental and integral transfer techniques,
4) an organizational structure of the stored data which minimizes the amount of control circuitry required for manipulation of the data, and
5) specific logical configurations that capitalize on the particular requirements of the control applications in question.

Active elements are used principally to direct data from the disk to the controllers and to output equipment, to modify data in any given channel, and to control the flow of data between channels.

A high degree of reliability is also promoted by using circuits operable over a wide range of parameters, by underrating circuit components, and by eliminating components considered inherently unreliable. Fail-safe operation is achieved by placing the computer in parallel with the process, *i.e.*, so that it controls only the set points of the controllers.

Over-all system performance depends not only on techniques for minimizing the probability of occurrence of a malfunction but also on rapid detection of a malfunction when it occurs.

To serve this end, the entire disk system is periodically and automatically given a test problem, and there is also provision for the insertion of special diagnostic programs by the system operator to allow any detected error to be traced to the process, including controllers, or to the computer.

The type of computer system described can serve in a test and evaluation phase as a process analyzer to determine the feasibility of computer control and as a simulator to investigate the effects of different types of control schemes. It can also function as a fixed-program process-optimization control computer. Though a single machine can be provided with both capabilities, the economics of a particular situation may be such as to justify the use of separate computers, one a flexible analytic computer, and the other a relatively inflexible fixed program computer for control optimization. Each of these machines would, of course, be less expensive than the machine with both capabilities.