Process Control Concepts

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Abstract

Many technical phrases are used rather loosely today when the interplay between computers and processes is discussed. These phrases are defined and their intended meaning is made clear by examples. Described are the philosophy behind the use of computer control over a generalized process, the levels of sophistication in applying computer control, and the characteristics which make a process suitable for computer control. Several examples are given in detail to show the various ways in which justification for computer control has been established.

Introduction

IT WOULD BE PRESUMPTUOUS to tell you how to run an edible oil plant. But there is a new "tool" which process people are using and which might be applied to the oil and fat industry. This tool is called a Digital Computer, and it is very fast but very dumb. Therefore a new class of people, called programmers, is needed to write the detailed instructions for the computer to follow in calculating pay checks, checking income tax calculations, or keeping track of production inventory. The computers that do this work are called Data Processing Computers. Communication with these computers is achieved in several ways: punched cards, magnetic tape, paper tape, typewriter, etc.

The computers to be discussed are "first cousins" to Data Processing Computers and go by the name of Process Control Computers. They are designed to operate in process environments where one is likely to find extremes of temperature, humidity, or dust. Thus they are rugged. They have all of the input-output devices but, in addition, they have the means to communicate with the process.

"Contact sense" is the name given to the ability of a computer to sense the status of contacts located at the process. This gives the computer "yes or no" information, for instance, "Is gave valve no. 12 open or closed?" "Is tank no. 36 filled or empty?" or "Is motor no. 16 running or stopped?"

"Analog conversion" is the feature which allows a computer to accept a varying voltage, milliamp, or pressure signal and convert it into digital form in the computer. Thus all instrumentation signals from the process can be "scanned" by the computer, and this information can be stored in the computer memory or used to calculate production rates, plant efficiencies, or management reports.

"Contact operate" is the name of the computer function which allows the computer, through programming, to close contacts in the computer so as to operate devices in the process. With this ability the computer can start and stop motors, open and close valves, etc.

An "interrupt signal" is one which allows selected events in the process to call for immediate use of the computer in order to take care of some emergency situation. For instance, a float device may have a set of electrical contacts which will close when a tank level reaches a certain height. These contacts would be connected to the interrupt terminals at the computer, and the "contact closure" would be a signal to the computer to "set aside" whatever it is doing and perhaps close several valves, open others, or adjust the process-operating position—whatever is appropriate to the situation.

Thus one can begin to see just how a Process Control Computer can communicate with a process, and it is this ability which makes it different from a "Data Processing Computer." See Figure 1.

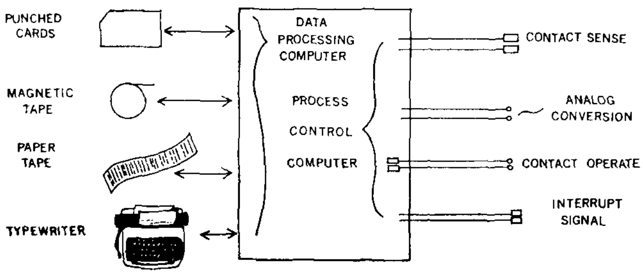


FIG. 1.

Next, how is a control computer typically used to help control a process? If a box is drawn and labeled "process," then one can think about the things that affect the process such as flows, temperatures, pressures, etc. The process variables which are under the operator's control are called, by the mathematicians, independent variables—or, by others, "knob" variables to indicate that they can be adjusted by the operator.

The desired results from the process may be production rate, yields, product specifications, plant efficiency, etc. This group is labeled "dependent variables" to indicate that their values are dependent upon the current operation of the process.

Then there are the class of variables which apply to a process and are not under anyone's control but cause changes in the process. These are called "disturbance variables," and they are the ones which cause the operators to make their adjustments to the controllable variables.

Typically the operator is guided by his instruments so that he can best apply his experience to make adjustments through set-point stations to optimize the operation of his process as shown in Fig. 2.

Processes have a way of becoming more complicated. Soon several operators are needed, located at different parts of the process, to keep track of things and make adjustments. Problems now arise because what is "optimum" for one part of the process may lower efficiency in another part of the process. In a batch process, such as brewing, batch scheduling becomes a problem. It is necessary to coordinate all of these asynchronous activities to obtain an over-all increase in plant efficiency.

A process control computer, with its ability electrically to "scan" all process variables in seconds, can be programmed to help the operators make the right decisions and bring about a level of plant control beyond the capability of human operators. This concept is shown in Fig. 3 and is called "operator-guide control."

With this arrangement the operator has another "tool"

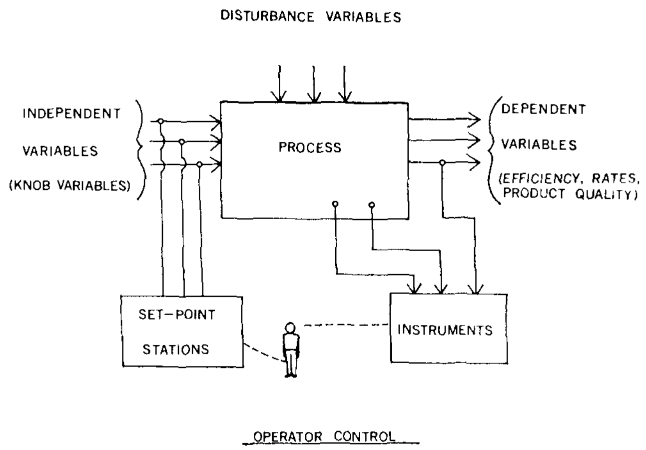
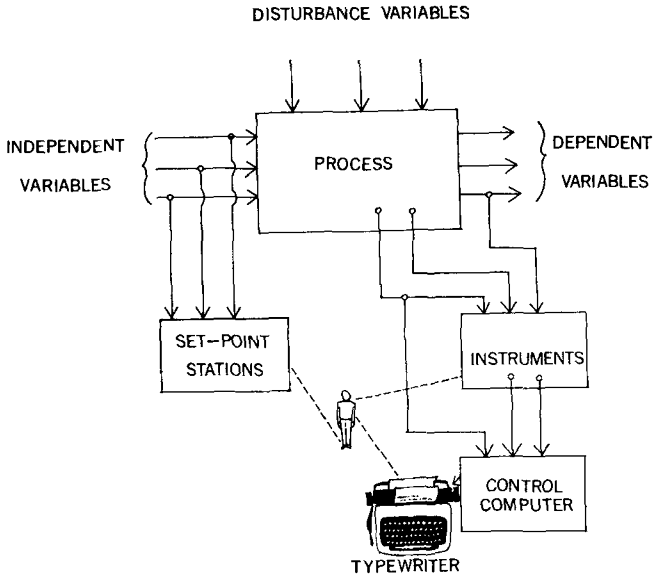


FIG. 2.



OPERATOR GUIDE CONTROL

FIG. 3.

to help him do his best control job. Frequently it is found that there are certain variables for which there are no instruments available to measure the value of the variable. In some of these cases several variables (for which there are instruments available) can be measured, and the value of the variable which cannot be measured directly nevertheless can be calculated.

The next step toward sophisticated computer control involves the idea of letting the computer adjust some of the set-point variables directly without going through the operator. This is called "closing the loop" because there is an electrical path from the process, through the computer and around to the process again, without going through the operator. This concept is applied on some variables where the control strategy can be precisely defined. See Figure 4.

Now the latest concept in process control is a further refinement which involves the removal of the fixed logic (electronics) control strategy from the set-point stations and expresses this strategy by mathematical relationships which can be programmed for the computer. This arrangement of equipment has been successfully installed on some processes and brings a degree of control not available by any other means. See Figure 5. It is called "direct digital control." To understand this concept, two values must be defined:

V_D = The desired value of a particular process variable, set-point value, which is dialed into a set-point station by an operator

V_A = The actual value of a particular process variable, which is being received by the set-point station from a primary sensing device at the process

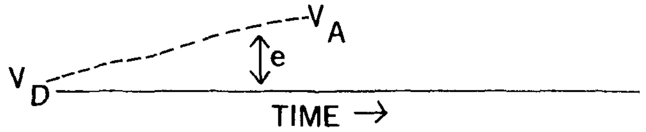
The "error signal" is defined as e, thus

$$e = V_D - V_A$$

Obviously if the desired value equals the actual value, everything is fine and no error signal is generated.

$$\text{If } V_D = V_A \text{ then } e = o$$

This can be shown by plotting



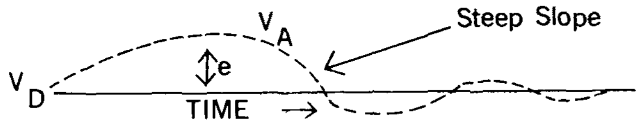
It is the function of the set-point station to translate the error signal into an analog correction signal (ΔV) that can be fed to a controller (such as a motor-operated valve) to return the actual value to the desired value.

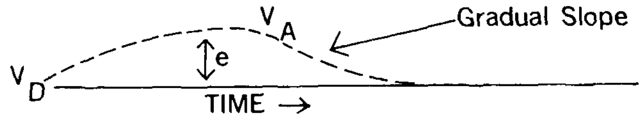
If there is a simple proportional control set-point station, the mathematical discription would be as follows:

$$\Delta V = k_o + \underset{\text{Prop.}}{k_1 e}$$

where k_o is the constant term and
k_1 is a coefficient of proportionality

However, on some processes, proportional control is not good enough so a more sophisticated scheme must be used. The rate at which it is wished to return the actual value to the desired value is called "slope."

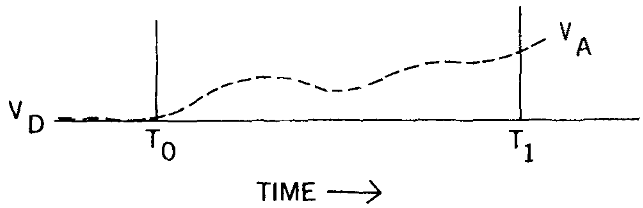




Now rate can be added to the mathematical expression, and we have a two-mode set-point station:

$$\Delta V = k_o + \underset{\text{Prop.}}{k_1 e} + \underset{\text{Rate}}{k_2 \frac{de}{dt}}$$

Even this is not good enough for some processes so there is another concept which relates the length of time in which the actual value has been away from the desired value to the size of the corrective signal. This looks like



Here the area under the curve can be used as the measure that introduces the time period from T_0 to T_1 and again, mathematically, another term is added to the equation. Now there is a "three-mode set-point station:"

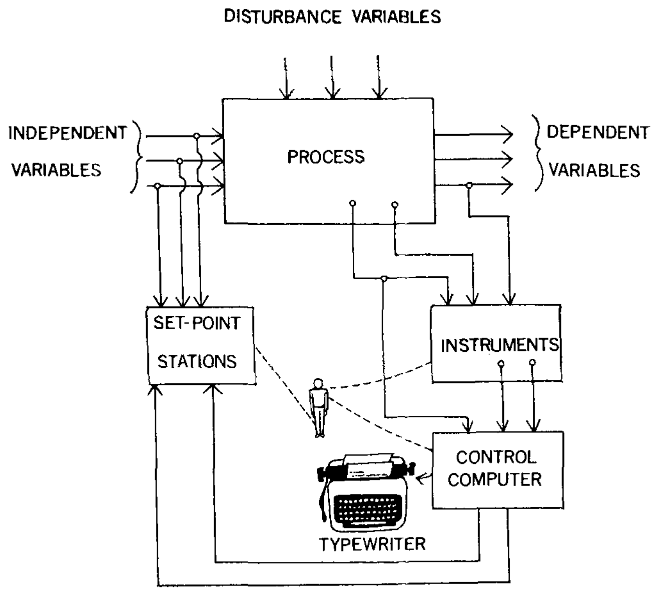
$$\Delta V = k_o + \underset{\text{Prop.}}{k_1 e} + \underset{\text{Rate}}{k_2 \frac{de}{dt}} + \underset{\text{Reset}}{k_3 \int_{T_0}^{T_1} e\, dt}$$

The exciting concept implicit in "direct digital control" is the fact that this mathematical expression of control strategy can be made into a digital computer program, and the adjustment of the k values can be made automatically to fit the present operating situation at the process. This is like having an instrument engineer continually "tuning up" each set-point station at the process panel-board on a 24-hour basis by using the second-by-second changes of the process as his guide.

Obviously this is outside the realm of human capability, but it is exactly what the Process Control Computer is designed to do. People who have used direct digital control are now talking about "nonlinear rate control" and "nonlinear reset control," where the value of the k coefficients are dependent, in turn, on other variables.

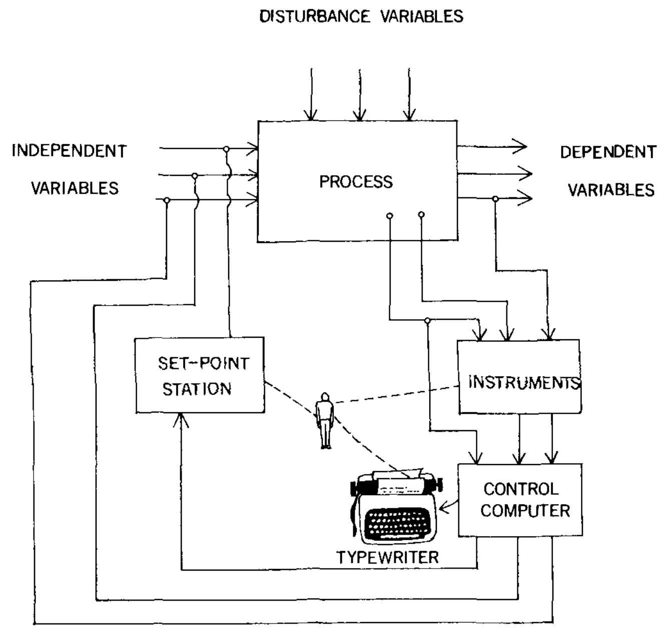
Appendix

The following is a list of the major potential computer control application areas in a general edible oil processing and manufacturig operation.



CLOSED-LOOP CONTROL

FIG. 4.



DIRECT DIGITAL CONTROL

FIG. 5.

Raw-Material Scheduling. Raw material for the plant comes by rail tank-car or tank trucks in liquid form. The plant processes both animal oils (lard and tallow) and vegetable oils (soybean, corn oil, safflower oil, cottonseed oil, and peanut oil). Scheduling of these raw materials; processing chemicals such as caustic soda, nitrogen, bleaching clays, etc., and product materials such as cartons, labels, containers, etc., represent a complex operation that must be tied closely to the manufacturing function.

Since most of these materials are ordered in bulk quantities from corporate headquarters, this suggests a teleprocessing hookup. There is some limited control locally as to the exact time a shipment will arrive at the plant site. This scheduling, at the headquarters and plant level, would lend itself to an optimization program for a computer. Each truck or rail car shipment is weighed full and empty as part of the raw material control function. These weight signals could be sent directly to a computer for accounting purposes and the preparation of inventory, vendor payment, or underweight documents.

Crude Oil Storage. A real-time inventory of crude oil can be maintained through the monitoring of oil-flow measurements to and from each storage tank. A cross-check can be obtained from tank level instrumentation. Since most of these tanks must be steam-heated, allocation of storage space to conserve steam energy becomes a mathematical optimization problem.

Refining Operation. Refining is accomplished by batch processing, based upon a "lot analysis." The calculation of caustic soda additions and the actual injection of the correct amount can be directed by computer control, and the lot treatment history can be logged automatically. Centrifugal scheduling to improve electrical power consumption may be another application.

Refined Oil Storage. Refined oil is stored in the blended condition. Tanks must be continually agitated as well as heated under carefully controlled temperature limitations. Computer monitoring of all temperatures and flow activity will provide a means of alarming an operator when adverse trends begin to develop. The problem is complicated when realized that tank levels can change and this upsets the heat transfer characteristics at the same time that a constant temperature is most desirable.

Blending of crude oils, with certain defined characteristics, subject to the restrictions of tolerance in blended specifications and in the required quantities, becomes a classical linear programming application.

Bleaching. Batch processing of oil blends require temperature control within pre-calculated limits, de-aeration under vacuum, followed by extensive filtering. An optimization is possible to obtain the largest amount of filtered oil stock of the desired color by using the minimum amounts of bleaching additives.

Winterizing. This is a controlled temperature process on cottonseed oil to remove crystals of supersaturated glycerides through filter presses to produce nonclouding salad oil. Economics and product demand will determine the split between salad oil and shortening in any one run. Here again an operator-guide type of report can improve communications between the processing and manufacturing departments to effect the best control strategy.

Hydrogenation. Both the hydrogen gas plant and the hydrogenation process itself are subject to critical control over temperature, flow, and pressure. In addition to the above variables, the type of catalyst used, its amount, and its state of activity must be considered when one is aiming for certain end-point product specifications. The hydrogenation process, with its critical temperatures and pressures, its continuous nature and short residence time, and its sensitivity to subtle changes in refined oil stock, seems to indicate its candidacy for the concepts of Direct Digital Control strategy.

Quality Control. All of the repetitive type of calculations, made in the laboratory, can be quickly made by the computer, given the input raw test data. With a digital computer it may be possible to alter or eliminate certain routine test work. This means that it may be possible to calculate test results rather than execute the routine analysis. A case in point is the procedure of making trial blends of basic blended stocks to meet end specifications. It should be possible to replace this physical simulation with a mathematical simulation by means of regression analysis, based upon blended stock analysis. "Laboratory trial blending" is a time-consuming activity which could be eliminated with the use of a computer.

Other analytical instrumentation, such as PH meters, vapor-phase chromatographs, refractometers, etc., and laboratory techniques, such as the determination for Solid Fat Index, Iodine Value, congeal point, saturation point, end-point chemistry, melting point, etc., can be partially automated by allowing the computer to monitor the analog signals and run the routine calculations.

Deodorization. Here is another process that is carried out under elevated temperatures in a vacuum to remove volatile impurities. It is important to maintain a history of the process activity related to product identification to assure that the proper precautions have been observed to prevent exposure to oxygen. This type of quality control record can be obtained automatically by "process monitoring" with a computer. All deviations from normal practice can be recorded and questioned if desired.

Utility Control. Logging of power-house instruments can be done by computer scanning of existing instrumentation. By using the concept of operator-guide control, the powerhouse operator can be alerted to forthcoming unusual plant power demands or be guided to the most economical boiler steam-flow assignments according to operating conditions or fuel availability. Sometimes "dump gas" is available at a least-cost price, and its use will represent a substantial savings over oil fuel if adjustments can be made fast enough.

The favorable utilization of electric power to take advantage of pricing structures is another possible source of savings if the plant operation can be adjusted fast enough without sacrificing process standards.

Net-Weight Monitoring. The most promising application concerns the many filling operations in putting the final products (peanut butter, lard, vegetable shortening, salad oil, oleomargarine, etc.) into containers. The obvious benefit is being able to adjust the stroke of the filling mechanism to counteract the changes of product density or container weights. Each filling machine has a fill adjustment designed for operator control. It is now feasible to sense container weights as they progress in the filling line and scan this signal with a Process Control Computer.

Once sensed by the computer, the analog weight signals can be converted to digital form and combined mathematically to detect an early trend toward high- or low-fill condition. This real-time information can be reported to the operator (via electric typewriter), or the computer can produce a corrective signal to drive an output device, such as a stepping motor, attached to the filling device adjustment mechanism. Individual net weights can be obtained by sensing container net weight and subtracting this amount from the filled weight of the proper unit. With the tremendous scanning capability of the 1800 control system, one would expect to pick up both tare and gross weights on several filling lines for each unit of product.

The savings in product, although intangible before a computer installation, can easily be determined once the system is installed and operating. The potential savings on this one application alone could more than justify the computer rental and perhaps only occupy 30% of the computer time which is available.

Management Information System. By the gradual implementation of these topics, a body of knowledge is built up within the computer which is the most timely source of plant-operating information. Production planning and inventory-control functions can be conducted with a high degree of sophistication when it is done with up-to-date plant information from the computer, coupled with order information as to what products to make and in what amounts.

When two production runs of the same product can be combined, the unit manufacturing cost is reduced substantially. Real-time cost accounting, which is now within reach via computer, can provide the break-away from the restrictions of traditional methods and provide a new measure of plant efficiency.

• *Obituaries*

B. Preston Harper, president of Southwestern Laboratories at Dallas, Texas, died July 18 at his home.

Leo D. Jones, of the Sharples Corporation, Philadelphia, died July 21, 1968.