

# DIGITAL COMPUTER APPLICATION IN PROCESS CONTROL

M. F. ABD-EL-BARY AND SRIRAM CHARI  
*New Jersey Institute of Technology*  
Newark, NJ 07102

WITH THE RAPID DEVELOPMENT and extensive use of Direct Digital Control (DDC) in industry, smaller versions of digital computers equipped with laboratory modules are being utilized increasingly in undergraduate Process Control laboratories to train chemical engineers in the theory and practice of digital control. It was pointed out by Waller [1], however, that the thrust of process control teaching is still directed toward very basic facts only, and that old textbooks were being used to a large extent. Newer textbooks and laboratory experiments should, therefore, emphasize computers and digital systems.

One of the chief reasons for the popularity of digital computers is the "amplifier-limitation"



**M. F. Abd-El-Bary** is an Assistant Professor at the New Jersey Institute of Technology. He holds degrees from Alexandria University, MIT, and Lehigh University. He has a strong interest in the area of digital control. His research work is primarily in the field of water and air pollution. (L)

**Sriram Chari** is an MBA student at the Harvard Business School. He has a B.S.ChE from Indian Institute of Technology, Delhi, and an M.S.ChE from New Jersey Institute of Technology. He was a Shift Engineer at Swadeshi Polytext Limited in Ghaziabad, India, before working on this project as a Teaching Assistant at NJIT. (R)

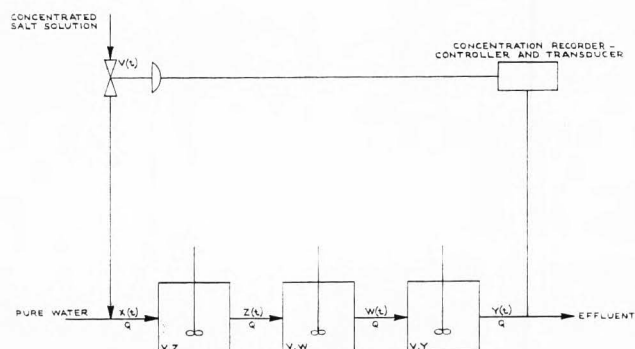


FIGURE 1. Schematic of three CSTR's

disadvantage of analog computers. Complex control systems, such as P-I-D Control, for example, require a large number of amplifiers, sometimes more than that which is available in smaller analog computers. A digital computer can resolve this difficulty by simulating the control logic through its software. In the Process Control laboratory at New Jersey Institute of Technology, a digital computer has been hooked up with an analog computer to give students an overview of the advantages and disadvantages of both computers in a single experiment.

An EAI-20 analog computer was used to simulate a system of three CSTR's in series. The first CSTR is fed with a brine solution stream and a fresh water stream. The salt concentration of the third CSTR outlet stream is controlled by regulating the flow of brine to the first CSTR, as shown in Fig. 1. The original set up involved only proportional control. The stability of the system is studied by observing its response to a unit step change in the set point. Writing a material balance and performing magnitude scaling leads to the final analog equation:

$$\frac{-d}{dt} [20Y''] = 6 [20Y''] + 2.4 [100Y'] \\ + 0.32 [500Y] + 0.16 K_c [2(500Y) - 1]$$

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where  $Y$  is the Laplace transform of the controlled variable, and  $K_c$  is the Proportional Controller gain (psi/mv). Fig. 2 shows the analog patch diagram corresponding to the above equation. The proportional controller gain ( $K_c$ ) was adjusted by means of potentiometer number 15, set at  $.016 K_c$ . Marginal stability resulted at a gain of 8 psi/mv, a value that was close to that obtained by analytical stability calculations such as the Routh test.

Recently, the department acquired a Digital MINC-11 minicomputer equipped with four laboratory modules: a preamplifier, an analog to digital (a/d) converter, a clock, and a digital to analog (d/a) converter. The two computers were connected so that the use of potentiometer number 15 of the analog computer was done away with, and the original input to the potentiometer became the input to the digital computer, which acted as the controller. For proportional control, the input analog signal was sent in through one of the a/d channels, converted to a digital signal by the a/d converter, and then multiplied by a constant ( $K_c$ ). The resultant digital signal was converted to its analog counterpart before the

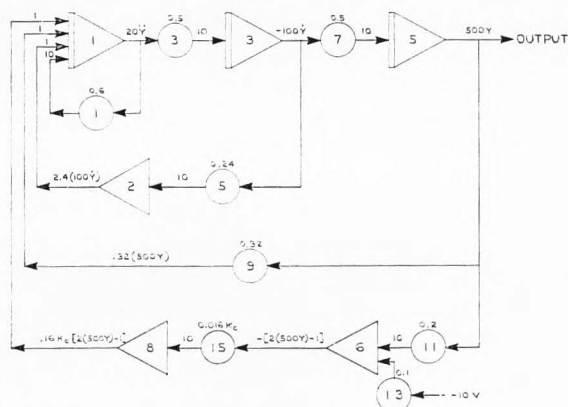


FIGURE 2. Analog Patch Diagram

latter was sent out to the analog computer as a substitute for the output of potentiometer number 15.

Addition of other modes of control such as Manual, Proportional-Integral, P-I-D, and P-D were made easily. For P-I, for example, the input signal was integrated by Simpson's Rule and the necessary additions and multiplications performed. For P-D control, on the other hand, the input signal was differentiated. In addition to achieving different modes of control, the digital computer was also used to monitor the analog computer

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output. Another channel of the analog/digital converter served this purpose.

### SAMPLING FREQUENCY

The frequency of sampling of the input analog signal was made as high as possible by using a loop in the BASIC program similar to a DO loop in FORTRAN. The clock module in the digital computer could have been used to obtain even higher sampling rates, but its disadvantage is that processing of the already collected data cannot simultaneously take place. Thus, the clock will allow the collection of 50 sample points at a very high rate, but will then *wait* for these data points to be processed and for the output signal to be sent out before collecting another 50 sample points. Between two processings enough time elapses to render a fast process unstable.

In the sampling method adopted in this experiment, one sample point ( $V_2$ ) was collected at the start of each loop, and used along with the last sample point ( $V_1$ ) to perform differentiation and other operations. On the basis of these operations an output signal was formulated and sent out, and the next loop began with the collection of a new data point. This new point was stored as  $V_2$ , and the old value of  $V_2$  transferred to  $V_1$ . This way, the two latest sample points are processed in each loop. A sampling rate of approximately one sample every 0.12 seconds could be achieved by this method. In addition, a PAUSE statement was incorporated in the program to introduce a time delay, and thus vary the sampling rate. Therefore, the effect of the sampling frequency on the system response could also be studied.

### RUNNING

With the analog and the digital computers hooked up together, the digital computer was started first with the values of  $K_c$ , Integral Time ( $\tau_i$ ), and Derivative Time ( $\tau_o$ ) specified. At a preset time the analog computer was put on

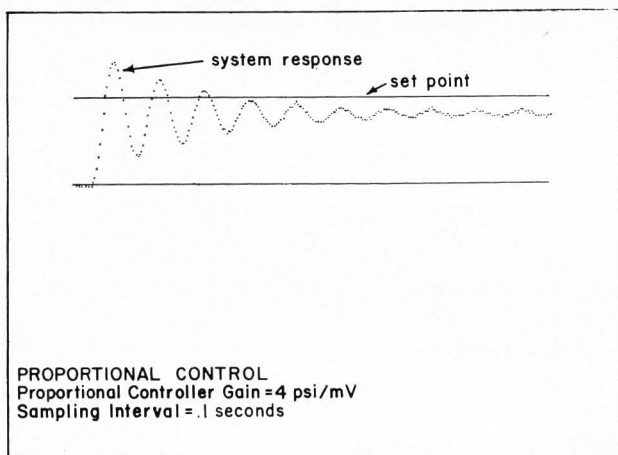


FIGURE 3

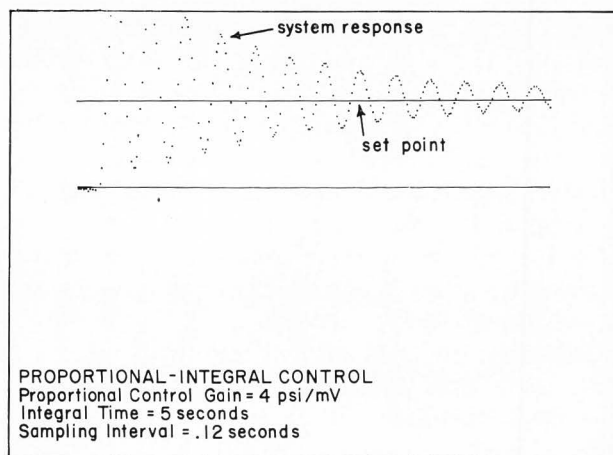


FIGURE 6

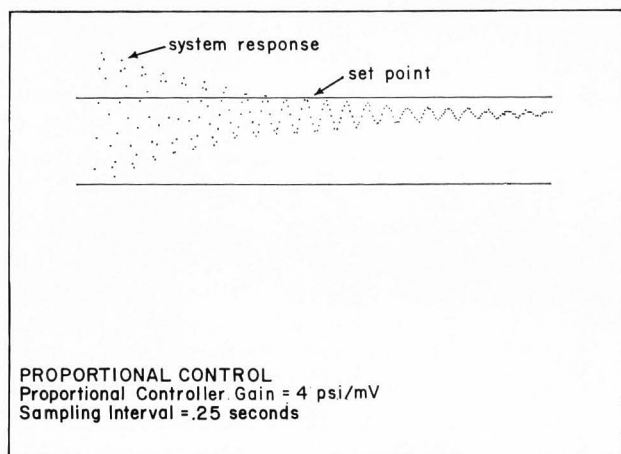


FIGURE 4

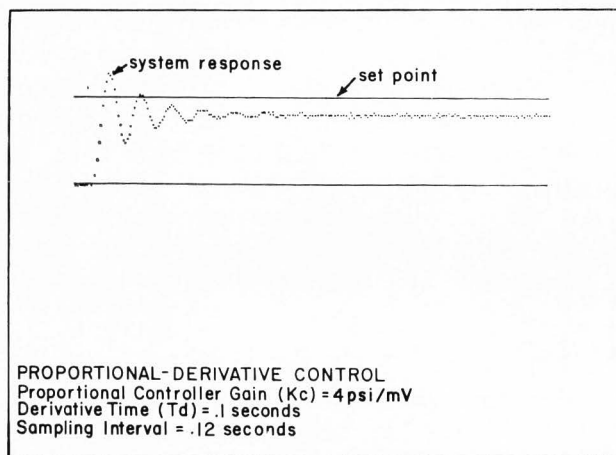


FIGURE 5

“Operate” mode. The response of the system could then be monitored on the video terminal. A Tektronix Hard Copy Unit was used for immediate reproduction of the video projection.

#### DISCUSSION

The most striking (and only apparent) disadvantage of digital control is that, at best, the sampling frequency only approximates continuous analog sampling. This disadvantage is very pronounced in controlling fast processes. For example, if the residence time in each CSTR is 0.5 minutes, the proportional controller gain ( $K_c$ ) for marginal stability is 5.25 psi/mv for a sampling period of 0.1 second, as compared to a value of 8.0 psi/mv obtained with continuous analog sampling. Increasing the sampling frequency to 0.25 seconds reduced the marginal stability value of  $K_c$  to 4.35 psi/mv. The use of discrete sampling through the addition of digital computer, therefore, decreases the proportional controller gain for marginal stability. Luyben [2] shows how this addition introduces, in effect, a process lag and hence increases instability.

This experiment allows the student to get a better understanding of control theory since the control is done through obvious software instead of the (black box) analog controller. Students can study the effect of varying sampling interval (through the use of PAUSE statement) on the performance of the system. By plotting the set point and the controlled variable on the CRT, the concept of offset, and oscillatory response can be shown much more clearly. In Figs. 3, 4, 5, 6, and

**THE MATHEMATICAL UNDERSTANDING OF  
CHEMICAL ENGINEERING SYSTEMS—  
SELECTED PAPERS OF NEAL R. AMUNDSON***Edited by R. Aris and A. Varma**Pergamon Press, 1980. 830 pages***Reviewed by John H. Seinfeld  
California Institute of Technology**

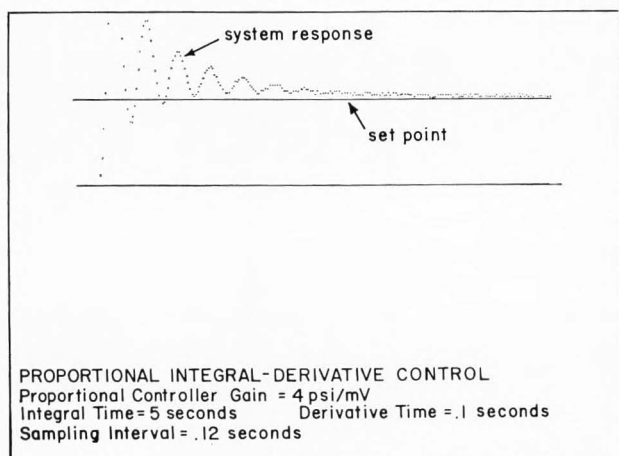
Neal Amundson has exerted a profound influence on the course of modern chemical engineering. As virtually a lone pioneer in the late 1940's and early 1950's, he opened the frontier of the mathematical understanding of chemical engineering systems. Although legions have rushed in behind him, a vast number of the Chief's own papers remain the seminal milestones along the path that has led slowly and steadily to a rigorous mathematical description of chemical engineering processes. This volume, prepared with love and care by Rutherford Aris and Arvind Varma, is a Baedeker for the traveller retracing that path.

Of over 2000 pages of Amundson's published papers, Aris and Varma have selected 800 for reprinting. For those papers not reproduced in their entirety, leading pages, with the usual abstract, and sometimes pages containing conclusions or summarizing statements, are included. The scope of the papers is impressively broad, including major contributions in ion exchange and chromatography, distillation, chemical reactor stability and control, polymerization reaction engineering, the modeling of fixed and fluidized bed reactors, steady state uniqueness and multiplicity of catalyst particles and chemical reactors, and the combustion of single carbon particles.

The modeling of physical systems is, as Aris has noted, an art and a craft, and Neal Amundson stands as the senior artist and craftsman in the modeling of chemical engineering systems. In his analysis of complex systems Amundson has always sought the mathematical description that captures the fundamental essence of the system's behavior, the art of selecting the proper balance between simplicity and reality. Once a model has been chosen, the elucidation of its properties can be attacked with all the heavy machinery of mathematics, the craft of the modeler. This

Continued on page 125.

7 the lower horizontal line represents the initial value of the variable, while the upper horizontal line represents the set point. Fig. 3 shows an offset, representing the behavior of the system with proportional control, and Fig. 4 shows more oscillatory response as the sampling frequency was increased. Fig. 5 represents the response with P-D control, showing better response over proportional control. Fig. 6 shows no offset with P-I control while Fig. 7 represents the response with

**FIGURE 7**

P-I-D control. The best response is clearly obtained with P-I-D control.

Another point to be taken into consideration is that a complex mode of control requires more amplifiers than can be provided by a small analog computer. This difficulty can be overcome by hooking up a digital computer together with it. In fact, there is no end to the modes of control that can be simulated by a digital computer used in conjunction with even as small an analog computer as an EAI-20.

**ACKNOWLEDGMENT**

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2. Luyben, W. L., *Process Modeling, Simulation, and Control for Chemical Engineers*, McGraw-Hill (1973).