SIMULATION OF SIMPLE CONTROLLED PROCESSES WITH DEAD-TIME

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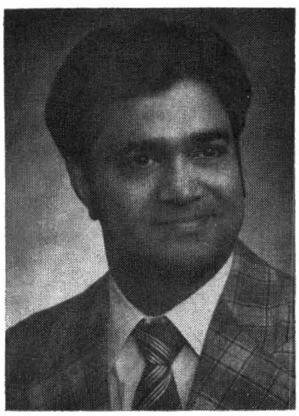
THE STUDY OF SYSTEMS with dead-time in undergraduate process control is important due to the fact that a large number of chemical process systems exhibit apparent dead-time characteristics and that the dead-time is detrimental to control. The topic dealing with the determination of closed-loop response of processes containing dead-time is typically not covered in under-graduate process control, possibly because the solution by Laplace transforms requires the use of Pade ap-



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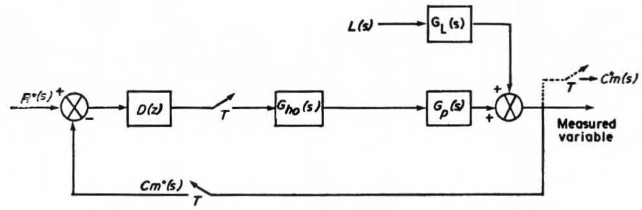

FIGURE 1. Typical sampled-data control system.

proximation for dead-time which makes the procedure lengthy and tedious. In this paper a computer-aided method is described which simplifies the procedure.

The method is based on the premise that the closed loop response of a sampled-data control system shown in Fig. 1, approaches that of the equivalent analog system (i.e., one without samplers and zero-order hold) as the sampling period is reduced. Thus, by suitable selection of the sampling period, the conventional (analog) control system can be analyzed by the z-transform method.

SYSTEM EQUATIONS

The scope of the program described in this paper is limited to the analysis of simple processes containing one or two time constants, a gain, and a dead-time element.

The closed-loop pulse transfer function of the sampled-data control system shown in Fig. 1 is

$$C(Z) = \frac{D(Z)\, G_{ho}G_p(Z)}{1 + D(Z)\, G_{ho}G_p(Z)} R(Z) + \frac{G_L L(Z)}{1 + D(Z)\, G_{ho}G_p(Z)} \quad (1)$$

The terms in Eq. (1) are indicated in Fig. 1.

The sampled-data system can be analyzed either for set point changes or for load changes. For set point changes, the expression for R(Z) is of the form

$$R(Z) = \frac{a + b Z^{-1} + c Z^{-2}}{d + eZ^{-1} + fZ^{-2}} \quad (2)$$

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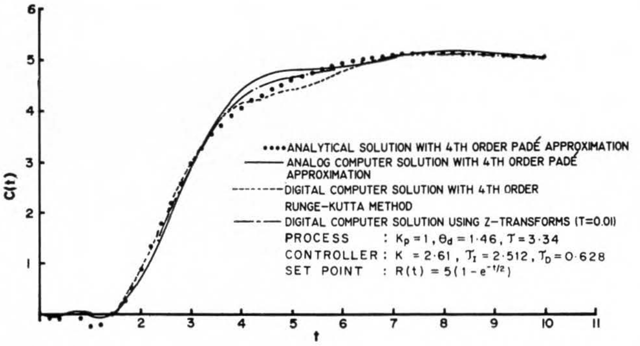

FIGURE 2. Set point response of the equivalent analog control and sampled-data control systems.

where a,b,c,d,e,f are user selected constants.

The appropriate expressions for D and G_p are inserted in Eq. (1) and the resultive equation is simplified to give

$$C(Z) = \frac{C_1 + C_2 Z^{-1} + C_2 Z^{-2} + \ldots}{D_1 + D_2 Z^{-1} + D_2 Z^{-2} + \ldots} \quad (3)$$

The constants in Eq. (3) are functions of the process parameters (K_p, θ_d, τ or K_p, θ_d, τ_1, τ_2), controller parameters (K_c, τ_I, τ_d) and the sampling period, T. Eq. (3) upon inversion by long division gives the closed-loop response at the various sampling instants. The load response of the process can be similarly evaluated [1].

PROGRAM DEVELOPMENT AND TESTING

A digital computer program written in double precision Fortran to solve Eq. (3) has been developed and tested. A listing of the program is available from the authors upon request. The user must specify as inputs the parameters of the process and controller, whether set point response or load response is desired and the sampling period.

The closed-loop response of an illustrative process is shown in Fig. 2. Also shown is the digital computer solution based on fourth-order Runge-Kutta integration and the analog computer solution based on the fourth-order Pade approximation. The sampling period for the z-transform-based solution is 0.01 time units. It may be observed that the sampled-data system approximates the conventional system well.

The z-transform based computer program should be useful in undergraduate process control. The undergraduate student, of course, will probably not be able to handle z-transforms. However, all that the student needs to know for the purpose of executing the program is the nature of the input data needed and the format of the results to be expected. □

REFERENCE

Deshpande, P. B., R. H. Ash, *Elements of Computer Process Control with Advanced Control Applications*, ISA, 1981; Prentice-Hall, 1983.

ChE book reviews

ELEMENTARY CHEMICAL ENGINEERING, Second Edition

By Max S. Peters, McGraw-Hill Book Company, NY (1983) $32

Reviewed by E. V. Collins
Iowa State University

The text covers the traditional topics of stoichiometry, unit-operations, chemical technology, and plant design. A complete nomenclature table is found at the beginning of each chapter where appropriate. Since this text is intended for students with no calculus background, there is no coverage of unsteady-state conditions.

This text is very well suited to a freshman level over-view course of the field of chemical engineering. We have used the first edition of this text in a survey course for other engineering disciplines. Worked out example problems are well chosen and used liberally throughout the text. Homework problems are available where appropriate, covering rather a wide spectrum of difficulty. Five homework problems are indicated as appropriate for computer solution. These cover a variety of applications, e.g. look-up table preparation, an iterative solution for a fluid flow system, and a matrix solution for a material balance problem.

The author used parallel solutions to example problems in first the American engineering system and then the SI system of units. It is unfortunate that the physical properties tables in the appendix are all given in American engineering system of units. This perpetuates the use of the American engineering units, since all data must be converted to the SI system of units. □