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PC-Oriented Software for Process Control Education*

MING RAO†
H. QIU
G. R. DONG
H. C. KIM
Y. YING
H. ZHOU
Department of Chemical Engineering, The University of Alberta, Edmonton, Alberta, Canada T6G 2G6

A software package for teaching chemical engineering students 'process control' using personal computers has been successfully developed at our department. This computer package covers a wide spectrum of control engineering, including time domain analysis, frequency domain analysis, root locus technique, stability criterion, linear system analysis and industrial process control applications. This software has been developed in such a way that the user can easily modify the parameter setting, figure scaling, function selection and the process model selection, and the programmer can easily add, delete, debug and compile subprograms. The program has been used to teach process control to senior undergraduate students and graduate students. Through using this package, students can gain practical experience on simulation and computer-aided design.

INTRODUCTION

IT HAS been widely recognized that process automation is a key element in making industries internationally competitive. Interdisciplinary in nature, process automation applies knowledge from electrical engineering, systems engineering and computer science to industrial processes. Modern industries have recognized the importance of process control to successful manufacturing.

Modern industries need engineers who are well educated in the most advanced computer technology to lead future industrial developments into a new era. It can safely be said that industrial processes in the future will require scientists, engineers and operators with considerable knowledge and experience of process control [1].

For engineering students, process control is one of the most difficult courses because it deals with abstract principles and requires a broad background. However, laboratory and computer simulation have greatly enhanced the possibility of successfully teaching this subject [2]. We are aware that the application of computer-aided teaching systems is an increasingly important feature of modern education. Computer simulation is very important for the analysis and design of control systems; it is also a convenient, low-cost tool for process control education. A teaching software package PCET (Process Control Engineering Teachware) has been developed at the University of Alberta for enhancing the quality of process control education. This software helps the students to gain a clear insight into theoretical concepts and practical computer simulation experience. It also stimulates students to investigate the detailed knowledge and to relate school learning to practical industrial situations.

In North America, the University of Alberta is the only institute that provides an education degree program in process control. Our department currently has 37 IBM personal computers in its microcomputer laboratory. A network system has been set up that links all computers in the department and also connects to the university computer network. The software developed for process control courses can be run by students in the microcomputer rooms located in the Chemical/Mining Engineering Building or using their own computers at home.

The development of this teachware also benefits university faculty members. For faculty members, this project can stimulate them to provide the best and most advanced teaching techniques in undergraduate education, and to help them maintain high standards and competence in teaching, research and public service.

The primary objective of developing this software is to develop an instructional software to strengthen undergraduate process control education at the Department of Chemical Engineering, University of Alberta, and to provide an inspiring learning environment for engineering students. This microcomputer-aided education laboratory

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† Ming Rao is Associate Professor and Director of the Intelligence Engineering Laboratory.

can be useful to a wide spectrum of teaching programs, including practical experience on computer-aided design, simulation and control. The objective of this project is to accomplish the following goals:

- To establish coherent undergraduate engineering curricula.
- To help students with educational problems at any time.
- To provide students with practical experience as well as clear insight into fundamental subjects.
- To provide an inspiring learning environment with the most advanced techniques.
- To help faculty members maintain high standards and competence in teaching, research and public service.

The objectives of the development of this software are consistent with the current activities of our department and will contribute to the university's efforts to achieve educational excellence and distinction. More importantly, it provides an integrated environment for course study and computer usage, resulting in a coherent curriculum.

The teachware developed has been used to teach process control to our senior undergraduate students in ChE 546 'Process Dynamics and Control' (Fall 1990 and Spring 1992), and for the graduate students in ChE 646 'Process Dynamics and Computer Process Control' (Fall 1991). The students attending the courses received copies of PCET and used it in their course studies. From PCET, they directly perceived theoretical concepts and gained practical experience. Students acknowledged that they have learned more from this teachware than others.

This software has also attracted the attention of industry. Several companies donated money and provided knowledge to support the development of this software package, which is used in both university and industrial plants. PCET was demonstrated at the IFAC (International Federation of Automatic Control) Conference on Advances in Control Education held at Boston in June 1991. It has gained much attention and appreciation from both academia and industry.

TEACHWARE PROFILE

The software is based on the content of 'Process Control Engineering'—a manuscript developed by us [3]. This teaching note was very carefully prepared in theory fundamentals and application techniques. The teachware, which consists of five simulation packages, are given on a diskette and can be used to solve many practical process control problems. With an interactive 'human–machine' communication and graphic display, this teachware package is capable of performing many functions.

Contents of the teachware

This teaching software has been developed mainly for undergraduate students, and aims to provide a new approach in the teaching of fundamentals of process control. As shown in Table 1, the PCET includes several subprograms: Time Domain Analysis (TDA), Frequency Domain Analysis (FDA), Root Locus Technique (RLT), Routh Stability Criterion (RSC), Linear System Analysis (LSA) and Industrial Application Cases (IAC). Each subprogram has several functions, with which the user can analyze the dynamics of the system, design the system and tune the controller.

Table 1. PCET functions

Acronym	Explanation	Functions	Applications
TDA	Time Domain Analysis	Open-loop system response Closed-loop system response PID control algorithms	Controller analysis System dynamic analysis System design Controller tuning
FDA	Frequency Domain Analysis	Nyquist plots Bode diagram Gain margin and phase margin	System dynamic analysis Stability analysis Controller design
RLT	Root Locus Technique	Root locus plots Critical points	System dynamic analysis Stability analysis Pole assignment
RSC	Routh Stability Criterion	Stability testing Routh array display Pole calculation	Stability analysis
LSA	Linear System Analysis	Controllability matrix Observability matrix Eigenvalue and eigenvector Matrix manipulation	Controllability analysis Observability analysis Eigenstructure analysis
IAC	Industrial Application Cases	Pulp and paper process Chemical process	Single loop control Cascade control Ratio control Decoupling control

Advantages of the software

The software package PCET has the following advantages:

High-level language environment. The software is programmed in a high-level language environment. It is implemented with the BASICA interpreter. Our main reasons for using BASICA are that it is (i) very easy to understand; (ii) suitable for teaching purposes; (iii) provides language commands for graphic functions; (iv) is the most economical computer language; and (v) a compiler is available for fast computation requirement.

User-friendly interface. PCET provides a user-friendly interface. Students can run the program without any knowledge of the software structure and the computer language. No commands are needed except for typing 'PCET' to start the program. The software uses a combination of the question-and-answer method and menu-driven interaction so that it provides a manual-free operation environment. For example, after typing PCET to start the program, the main menu is shown on the screen (Fig. 1). Pressing a number key (1–7) or selecting an item with a return will start a subprogram.

The user-friendly environment also appears in model selection. A polynomial model or a pole-zero model can be chosen by the user to represent the transfer function of a process. It is convenient for students to use the different models to analyze a system or to understand a concept. For instance, pole-zero model is more suitable for students to understand the concept of root locus, while a polynomial model is more appropriate for studying Routh stability criterion.

The parameter setting is convenient in PCET. After a set of parameters, e.g. PID controller parameters, are assigned, a confirmation is required, so that the user can correct the parameters. If the user wants to change the parameters after running a subprogram, he or she only needs to press a function key and select the parameter that needs to be changed.

In a subprogram, function transition can be done without recommencing the subprogram by pressing a function key, e.g. in FDA pressing function key 'F7' to obtain the Nyquist plot and 'F8' for the Bode diagram.

Powerful graphic capability. PCET has a powerful graphic capability that allows students to obtain results by means of both graphic display on the screen and hard copies from a printer or plotter. The graphic capability includes the response of an open-loop (or a closed-loop) system to a unit step input, Nyquist plot, Bode diagram, root locus and industrial application cases.

The graphical pictures can be automatically scaled by the computer or dimensioned by the user by a question-and-answer mode. If the user wants a detailed part of the picture on the screen, a function key is available for changing the dimension. By pressing this function key, the dimension the user required can be entered.

Integrated distributed intelligent system configuration. The integrated distributed intelligent system was originally proposed by the first author, and was developed to handle the integration issue for distributed intelligent systems [4]. It is a large knowledge integration environment, which consists of several symbolic reasoning systems and

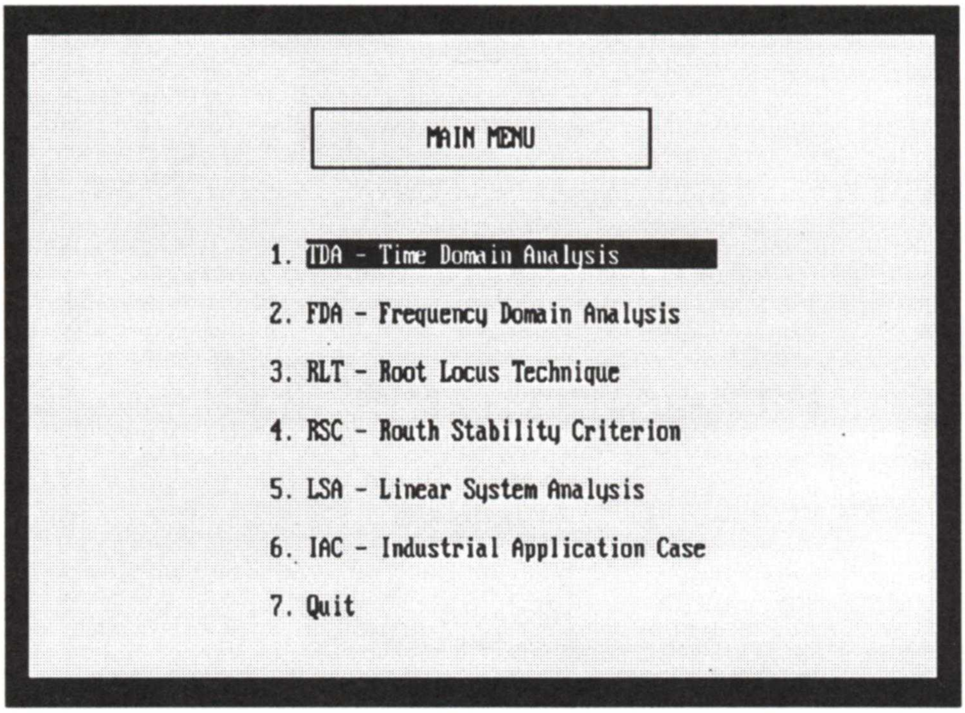


Fig. 1 Main menu of PCET.

numerical computation packages. These programs are controlled by a meta-system. In our teachware PCET, some individual subprograms, such as TDA, and others (see Table 1), are developed separately for different purposes, and a meta-system serves as an interface mechanism and a coordinator to communicate between individual software programs, and to build the human–machine interface. Such a hierarchical configuration enables us to add, delete, debug and run the subprograms separately. When a new subprogram is to be integrated into PCET, we only need modify the interface of the meta-system without interrupting other subprograms, which can also be integrated to run together whenever needed.

A global database is set up in the meta-system, which is a common data resource for all subprograms. The process model can be put in at any subprogram and shared with other programs. With this configuration data need only be input once to analyze the same model in different domains or with different methods. The models can also be saved for later use.

Industrial process control application case study. Chemical processes are very complicated, with a high concentration of advanced technology and operation automation. It is important for engineering students to have basic practical experience before they start their professional careers. Industry welcomes students who have more practical experience. Unfortunately, no such application cases have been implemented in an education-oriented software.

PCET has been developed with financial aid and technology support from industrial companies, and this has helped us to implement such a high-quality teachware for our students.

Some typical industrial application cases are included in PCET in order to combine theory with practice, and to link abstract mathematical models with real industrial processes. For example, with a model of typical paper machine headbox control system, some typical industrial process control configurations are introduced. We implemented single-loop control, cascade control and decoupling control configurations in this model, with which the system performance can be studied.

ILLUSTRATIONS

We designed five computer simulation laboratories with PCET for senior undergraduate students on process control courses; each simulation corresponds to a chapter in the text manuscript [3], which includes 24 projects as shown in Table 2. In these computer simulation laboratories, subprograms TDA, FDA, RLT, RSC and IAC are relevant. As an example, TDA and its laboratories are described as follows.

Subprogram TDA was developed for the analysis and design of a system in the time domain. Its functions include open-loop system response analysis, PID controller algorithm analysis and closed-loop system response analysis, with which controller analysis, system dynamic analysis, control system design and PID controller tuning can be done. To analyze the system behavior, the closed- or open-loop responses of the system to a unit step input can be plotted on the screen or from a printer with an autoscaling or a specified scaling. The controller action can also be analyzed. According to the system response behaviour, the controller may be designed by means of a trial-and-error method.

Briefly, TDA facilitates simulation for the analyses and design techniques in the time domain which is used in Laboratory 1 (analysis and design in the time domain) and Laboratory 4 (controller design and tuning). Laboratory 1 has three phases including 10 laboratory projects. They are described in detail below.

Phase I: open-loop system response

In this phase, we have taught not only such fundamental principles as open loop, closed loop and feedback, but additional important concepts such as process gain, time constant, damping ratio and time delay (dead time). The following three projects have been carried out. Several computer-controlled process control systems are used for experimental verification.

Project 1: open-loop dynamic response of first-order systems.
Project 2: open-loop dynamic response of second-order systems.
Project 3: open-loop dynamic response of different-order systems.

Phase II: PID control behavior analysis

The most common control law applied to the present industrial environment is the PID (proportional, integral and derivative) control algorithm, which is the basis of undergraduate courses in process control. Therefore, the function for analyzing the PID controller's action is included.

Four laboratory projects are performed in this phase.

Project 4: proportional control action (P).
Project 5: proportional and integral control action (PI).

Project 6: proportional and derivative control action (PD).
Project 7: proportional, integral and derivative control action (PID).

Phase III: control system design

A controlled process is composed of two sections: process and controller. One of the main tasks of a modern control engineer is to select a suitable control law for a specific operation and to link it together with the process. In this phase, students study control system design for several typical

Table 2. Laboratory projects (for undergraduate student course)

Laboratory	Phase	Project
Analysis and design in the time domain	Open-loop system response	Open-loop response for first-order systems Open-loop response for second-order systems Open-loop response for different-order systems
	Controller behavior analysis	Proportional control action Proportional-derivative control action Proportional-integral control action Proportional-integral-derivative control action
	Controller design	Controller design for a first-order system Controller design for a second-order system Controller design for a third-order system
Stability and root locus technology	Routh criterion	Routh criterion and pole calculation
	Root locus	Root locus drawing Stability determination of systems PD controller design
Frequency domain analysis		Nyquist plot and Bode diagram drawing Controller design
Controller design and tuning	First-order system	P controller design and tuning for first-order system PI controller design and tuning for first-order system
	Second-order system	PI controller design and tuning for second order system PID controller design and tuning for second order system
Industrial process control and application	Pulp and paper process	Single-loop control system Cascade control system Decoupling control system
	Chemical process	Ratio control system

processes, and construct an appropriate closed loop system.

Three laboratory projects are carried out.

Project 8: controller design for a first-order system.
Project 9: controller design for a second-order system.
Project 10: controller design for a third-order system.

Laboratory 4 has two phases for controller tuning. The students are required to design a controller using the Cohen and Coon method for a specified system before going into the laboratory. With the designed controller parameters as the initial values, controller tuning is done by trial-and-error method. The practical rules of tuning controllers, and selecting the direction of their action are also tested [3, 5–6]. The specified systems include a pressure control system with the P controller, a flow control system with the PI controller, a tank level control system with the PI controller and a temperature control system with PID controller.

Here we present a case of a closed-loop system design as an illustration. The open-loop process transfer function is specified as

$$G(s) = \frac{K_0}{(T_1 s + 1)(T^2 s^2 + 2Txs + 1)} e^{-\tau s}$$

and the PID control algorithm is

$$G_c(s) = K_c[1 + 1/(T_i s) + T_d s]$$

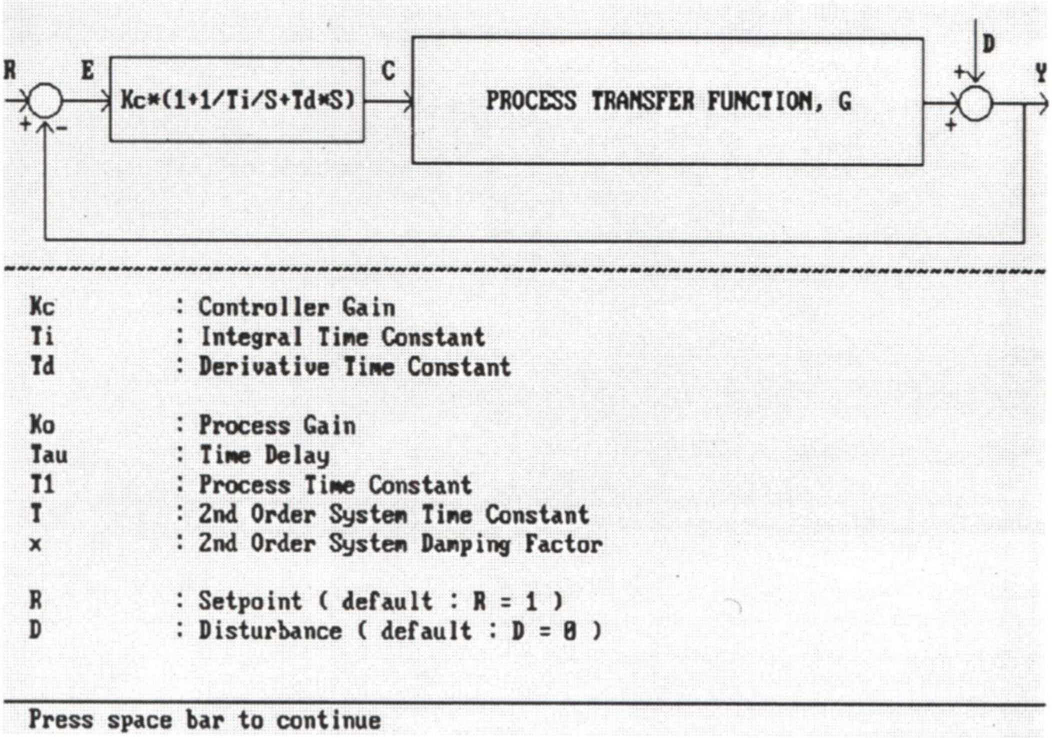
As an example, we select a third-order system with the following parameters:

$$K_0 = 2.5,\ T_1 = 3,\ T = 4.2,\ x = 0.5,\ \tau = 1$$

and a PID controller with the parameters

$$K_c = 0.6,\ 1/T_i = 0.2,\ T_d = 3.5$$

After starting PCET, select '1' on the menu (Fig. 1) to load the TDA program. The screen shows the system block diagram and operation instructions, as demonstrated in Fig. 2, while Figs 3 and 4 display the model selection and project selection manual. Following the instruction on the screen, key '3' is pressed for analysis of the closed-loop system. After the input data are confirmed, we can select the figure scale: autoscaling or specified scaling. Then the closed-loop response of the



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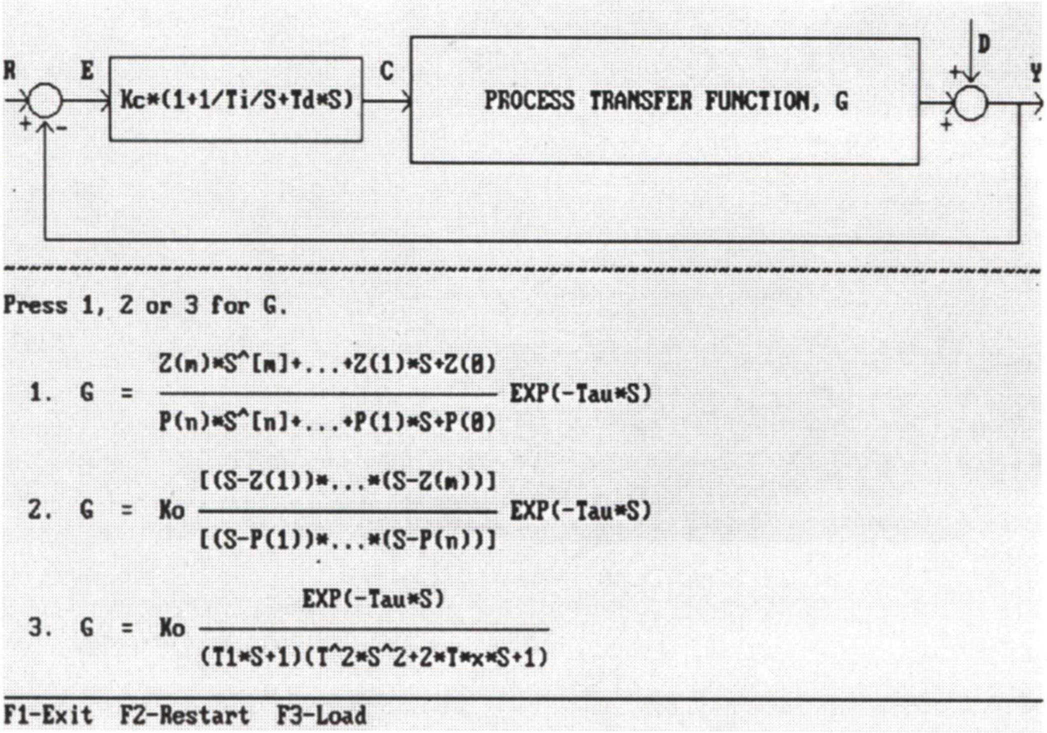
Kc         : Controller Gain
Ti         : Integral Time Constant
Td         : Derivative Time Constant

Ko         : Process Gain
Tau        : Time Delay
T1         : Process Time Constant
T          : 2nd Order System Time Constant
x          : 2nd Order System Damping Factor

R          : Setpoint ( default : R = 1 )
D          : Disturbance ( default : D = 0 )

Press space bar to continue
```

Fig. 2. System block diagram in TDA.



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Press 1, 2 or 3 for G.

               Z(m)*S^[m]+...+Z(1)*S+Z(0)
 1.  G  =  ----------------------------------- EXP(-Tau*S)
               P(n)*S^[n]+...+P(1)*S+P(0)

               [(S-Z(1))*...*(S-Z(m))]
 2.  G  =  Ko ------------------------------ EXP(-Tau*S)
               [(S-P(1))*...*(S-P(n))]

                         EXP(-Tau*S)
 3.  G  =  Ko ---------------------------------------
               (T1*S+1)(T^2*S^2+2*T*x*S+1)

F1-Exit  F2-Restart  F3-Load
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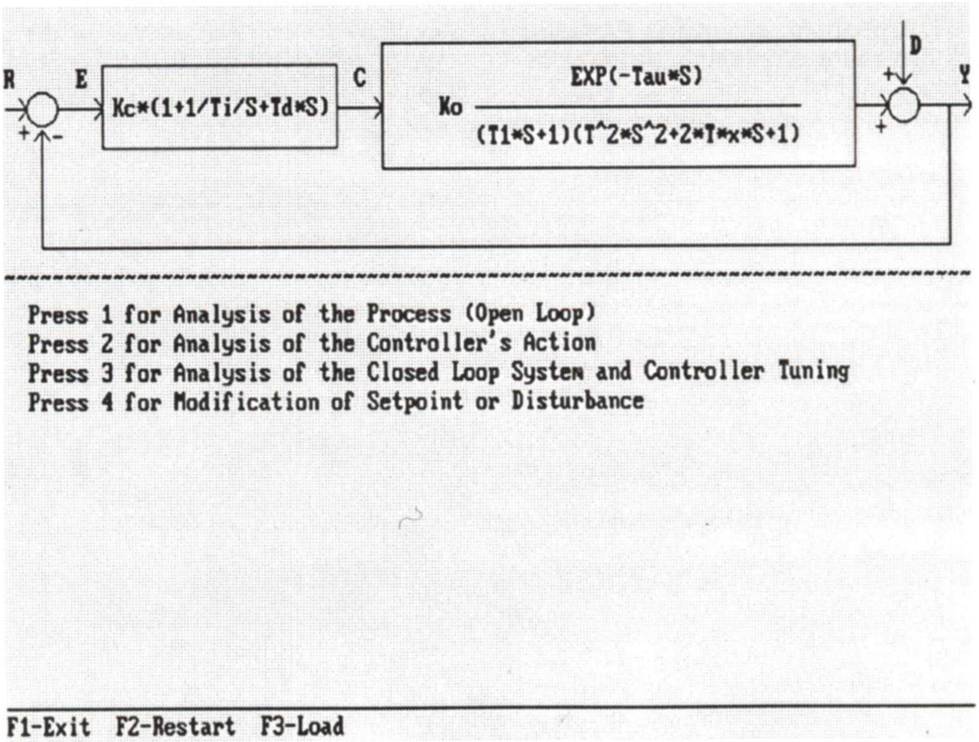
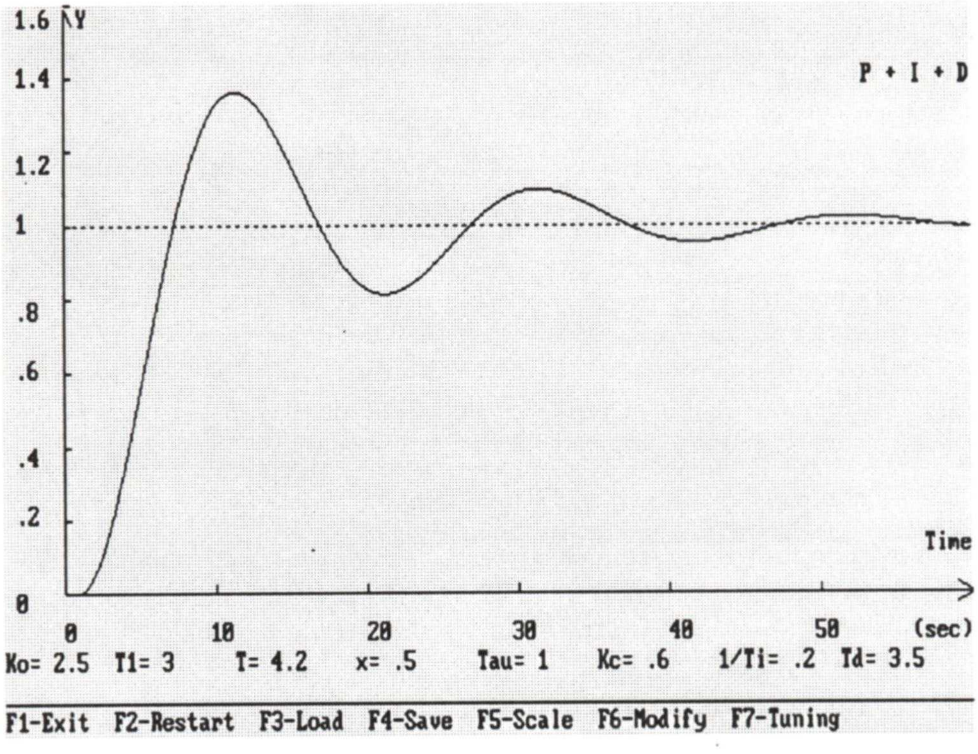
Fig. 3. Model selection in TDA.



Press 1 for Analysis of the Process (Open Loop)
Press 2 for Analysis of the Controller's Action
Press 3 for Analysis of the Closed Loop System and Controller Tuning
Press 4 for Modification of Setpoint or Disturbance

Fig. 4. Project selection in TDA.



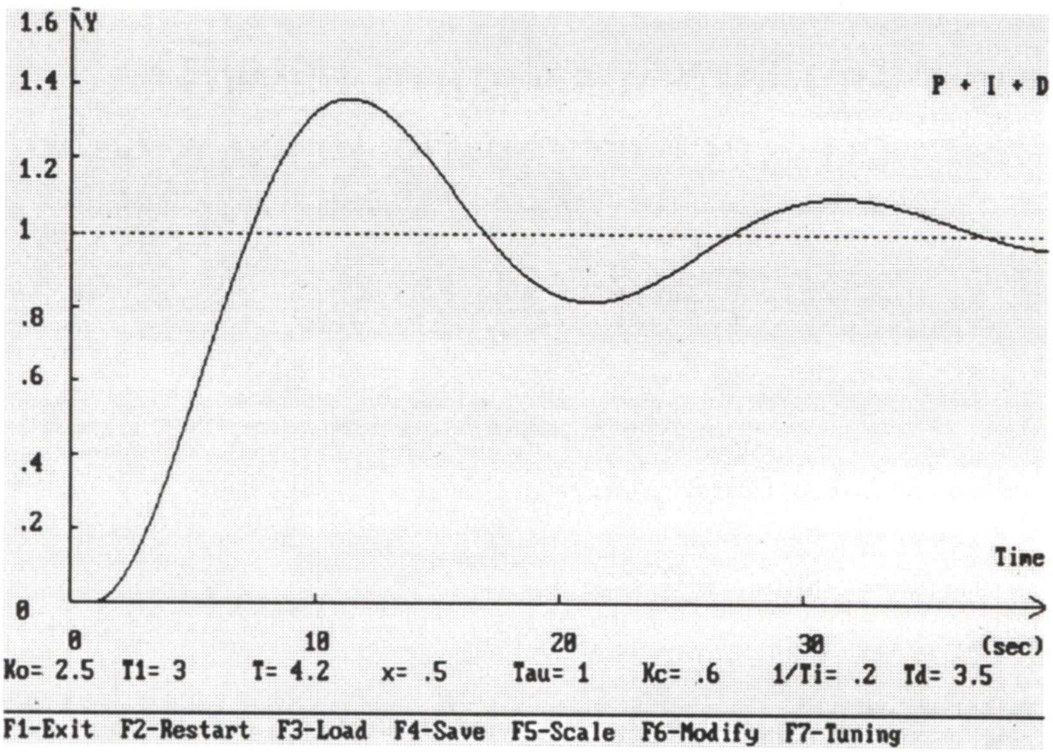
Ko= 2.5 T1= 3 T= 4.2 x= .5 Tau= 1 Kc= .6 1/Ti= .2 Td= 3.5

Fig. 5. System response of the example.

system to a unit step input with autoscaling is plotted (Fig. 5). It is easy to zoom in on a part of the plotted figure by pressing a function key; the result is shown in Fig. 6.

CONCLUSIONS

For engineering students, process control is one of the most difficult courses because it deals with abstract principles and requires a broad back-



Ko= 2.5 T1= 3 T= 4.2 x= .5 Tau= 1 Kc= .6 1/Ti= .2 Td= 3.5

Fig. 6. Zoomed plot of Fig. 5.

ground. However, laboratory and computer simulation have greatly enhanced the possibility of successfully teaching this subject. We have proposed and implemented a new approach to the teaching of process control courses. This methodology, which uses microcomputer-aided education software for teaching process control, has enhanced the process control curricula at the University of Alberta. The teaching software is useful for a wide spectrum of educational programs, including practical experience in computer-aided design, simulation and control. This new approach to the teaching of process control stimulates students who are readily able to relate school learning to the nearly real industrial practical situations. Such experience translates more directly to the real industrial environment. For the academic community, the advantage is that the methodology, which is not only low cost but also convenient to use, could help engineering students to gain clear insight into theoretical concepts. We are aware that the application and research of computer-aided education systems are increasingly important features of modern engineering education. Computer-aided education systems can assist students with educational problems, help them achieve practical experience and reduce their work pressure.

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