Use of *KRi* Dual Process Simulator
for Process Control Experiments
Model KI-100 & KI-101

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Acknowledgements

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INTRODUCTION

The advent of low-cost and yet powerful microprocessor-based single-station controllers and distributed digital control systems (DCS) has made it more convenient nowadays to implement advanced process control [1]-[5] to improve control performance and hence plant profitability. Advanced control techniques include feedforward, nonlinear, multivariable, dead-time compensation, stochastic, auto-tuning and adaptive control which are based on a combination of control knowledge and process dynamic models. They are new to engineers and operators and are sophisticated compared to the widely used proportional-integral-derivative (PID) controllers. It is therefore essential that adequate training be provided if they are to be routinely used in practice.

In this application note, we shall first review three principal methods of providing training to plant operators and engineers in the familiarization, commissioning, tuning and operations of advanced process control system. The first two which have been predominantly used are based on pilot plant and process computer simulation respectively. The third one which is based on an analogue simulator is limited in the range of selectable process dynamics. In the second part of this note, we shall present a new simulator based on a single-chip controller which largely enlarges the range of process dynamics and hence overcomes the previous limitations of analogue simulators.

NEED FOR TRAINING

Unlike a PID controller in which much knowledge and experience about its performance and operations are well known to operators and practicing engineers, little is known by them when it comes to an advanced controller. This is not only because it is new; it is also much more demanding in knowledge of process dynamics and characteristics of the advanced controller itself.

Take for instance the tuning of a Smith Predictor, which is a robust dead-time compensator [4]. If the process model can be approximated by a dead-time plus first order model, then three process model parameters, namely the dead-time, time constant and gain have to be determined. Unless an automatic modeling routine is available, which is not yet available in most commercial systems, the instrument/control engineer must learn how to make such an estimation using the process reaction curve. After this is done, the next non-trivial step is to determine the settings of the associated PI controller. This step is also different from the usual PI controller tuning as the dead-time is outside the main control loop and hence the Ziegler-Nichols procedure is not applicable. Instead, a Dahlin type controller synthesis [4] is more suitable. Engineers need to be familiar with all these new methods before they can become confident in applying and tuning the Smith Predictor.

Another example is multivariable control [3]. First, the transfer functions between the inputs and outputs of the open-loop process must be determined. This is already more complex than that associated with the single-variable Smith Predictor discussed in the previous example. Then the decoupler transfer functions can be computed to minimize loop interaction. The next non-trivial step is to determine the settings of the main controller which has to control the combined dynamics of both the process, the decoupler and the cross-coupling term. The fact that the main controller needs to be retuned after the decoupler is commissioned is not so transparent to the practising engineer. Likewise, the disconnection of the decoupler would mean that the loop is no longer optimally tuned, in addition to the loss of the decoupling function! This can be appreciated from analysing the block diagram of a multivariable control system as shown in Fig 1. Without decoupling, i.e. D12(s) = D21(s) = 0, the controller C1(s) needs to be tuned to the process dynamics given by G11(s), plus the interaction dynamics through G21(s), G22(s), G22(s) and G12(s), depending on whether C2(s) is on manual or automatic mode. With perfect decoupling, C1(S) then only needs to be tuned to G11(s) + G12(s) D21(s) and independent of G21(s), G22(s), C2(s). The need of training in the tuning and operation of a multivariable controller is evident.

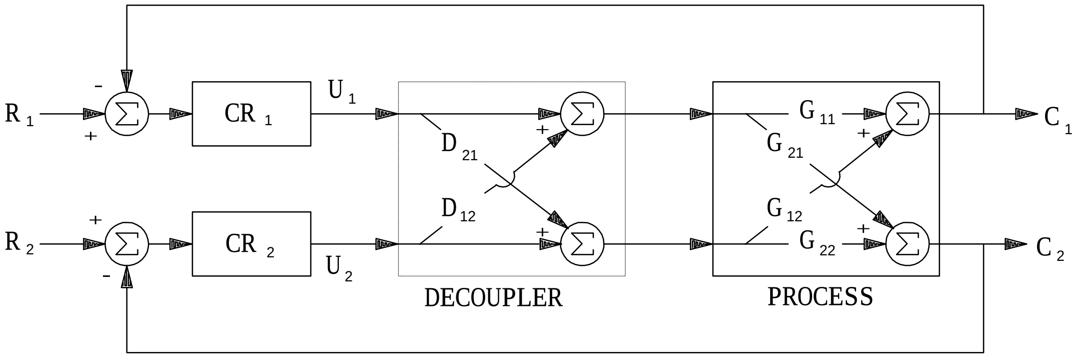

Figure 1 Multivariable control

MEANS OF PROVIDING TRAINING

The most basic means of providing training in the use of advanced control is the use of a suitable pilot plant. The pilot plant can range from a simple bench-top physical process such a level/flow control of a coupled tank, to sophisicated pilot-scale heat exchanger or chemical reactor. The obvious advantage is that it is quite realistic if it is a suitable one. The main disadvantages are its inflexibility, bulkiness and high capital cost. The use of pilot plants is thus usually limited to a small number of R & D and university laboratories.

The advent of process computers has made possible a second method of providing training. By physically wiring the controller output back to the extra inputs of the process computer, and making use of the spare computing modules provided for signal conditioning, various process models can be realized for testing the controller performance [6]. This allows the operators and engineers to be familiar with the advanced control interface and software features well before the actual physical process is constructed. The main disadvantages are that a fair amount of application software needs to be written and that it is not portable.

The third method is based on the use of an external computer simulator [6],[7]. The conventional means for this purpose is the analogue computer. It may be limited in the range of dynamics to be simulated; for instance a dead-time element can only be approximated. It is also expensive and time-consuming to set up the analogue patching. However, it is more portable than most pilot plants and it is suitable for use with modern single-station microprocessor-based controllers. An example of a more successful commercial analogue product is the Foxboro simulator. It is, however, limited to testing of single-loop and cascaded PID controllers and not designed for training of advanced control system.

MICROPROCESSOR-BASED SIMULATOR

The limitations of the analogue simulator could be overcome by the use of digital simulation. For operator training in the control of large processes such as power system, digital or hybrid computer based simulators are commercially available but they are very expensive. For the purpose of providing training in the familiarisation of advanced control, however, a low-cost personal computer with suitable A/D and D/A converters can be used to simulate various process models [6], [7]. The user would not find any significant difference compared to the real process as the input and output of the simulator are analogue signals and a high sampling rate is used in the implementation of discrete process simulation.

The advent of single-chip microcontrollers has made feasible yet another approach - the replacement of the microcomputer by a single-chip controller. Such a simulator, built around the Intel 8096 16-bit microcontroller with an on-chip 10 bit A/D and an external 12-bit D/A converter is shown in the block diagram of Fig. 2. The software modules have all been pre-programmed using the C language. Through a user-friendly and self-explanatory front panel as shown in Fig. 3, the user can freely select the combination of dead time, lags, oscillatory poles, integrator, non-minimum phase zeros and nonlinear gain to form the process to be simulated. It also provides two channels of input/output and crosscoupling lags can be selected to simulate a 2-input, 2-output multivariable process. A variety of lag elements, variable gain, choice of deterministic/stochastic disturbance and a time-scale speed-up request switch are also provided. The wide range of dynamic elements is indicated in Table 1. The low-cost, portable and flexible simulator is thus much more powerful than most commercial analogue simulators and could provide all the features of a microcomputer-based simulator [6], [7].

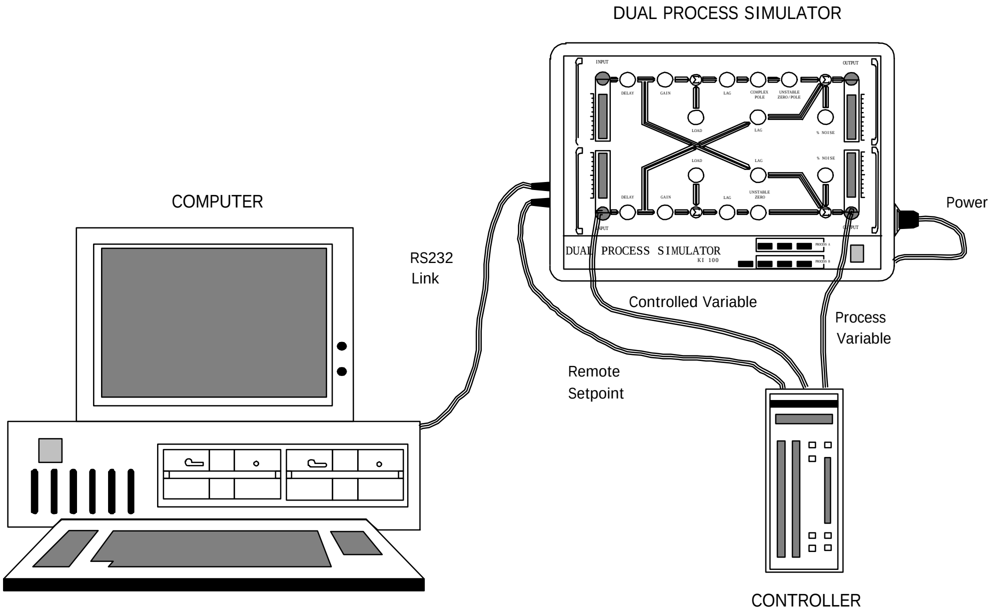

Figure 2 Set-up for testing commercial controllers

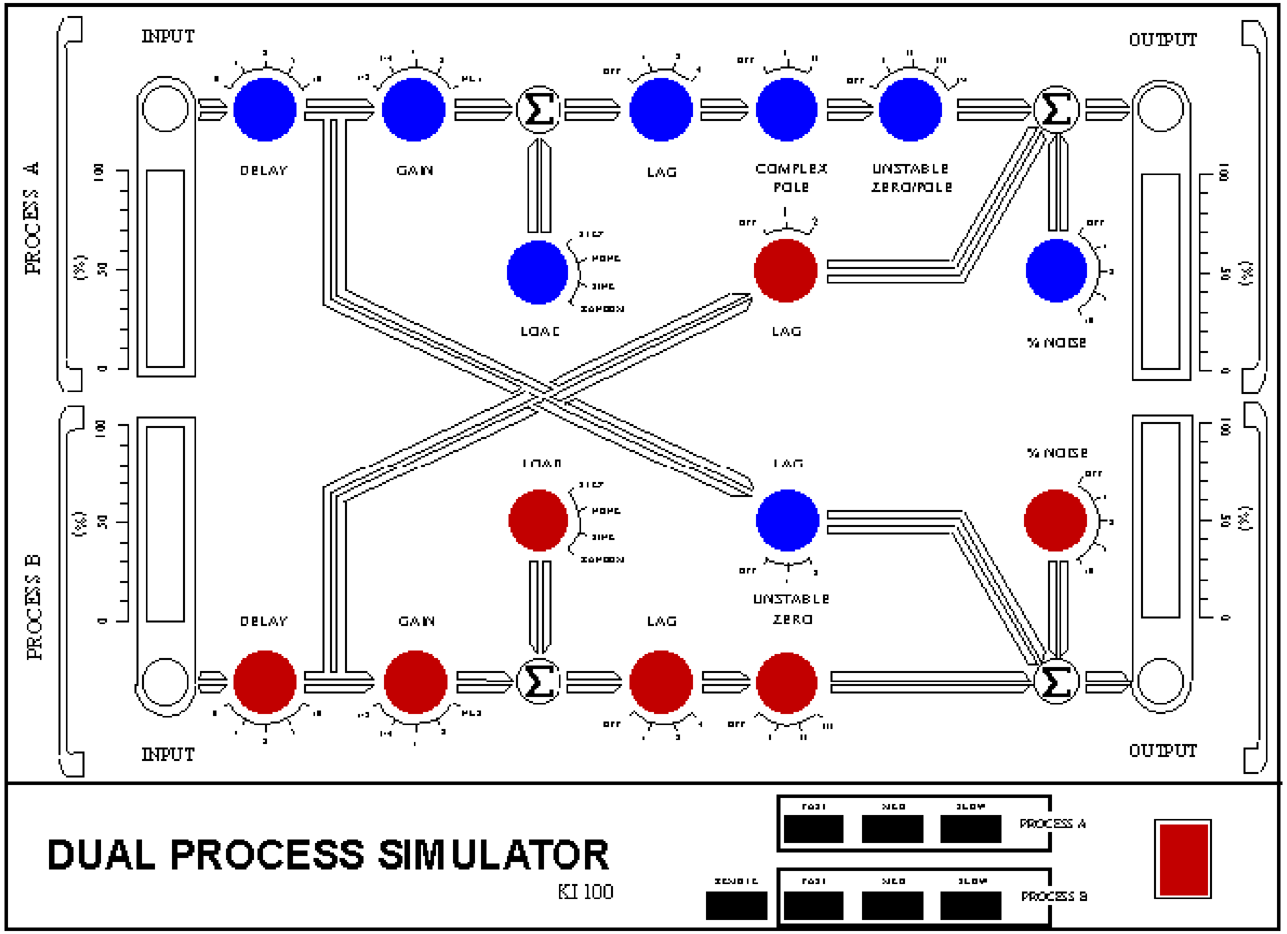

Figure 3 Front panel of process simulator

Table 1 Process Elements

Time Scale	FAST (x1), MED (x2)and SLOW (x5)
Dead time	1, 2, 5 and 10 (x delay unit[1])
Gain	0.5, 0.75, 1, 1.5, 2 and non-linear (NL1 or NL2)
Lag	$\frac{1}{(1+s)^n}$ where n = 0, 1, 2 or 4.
Lag(coupling)	$\frac{1}{(1+s)^n}$ where n = 0, 1 or 2
Complex pole	$\frac{1}{(1+0.25s+s^2)}$ or $\frac{1}{(1+s+s^2)}$
Unstable pole	$\frac{1}{s}$ or $\frac{1}{(1-s)}$
Unstable zero	$(1 - s)$, $(1 - 0.5s)$ or $(1 - 0.5s + s^2)$
Load	step, sine and random (magnitude fixed at 10% of full span)
Noise	max. magnitude 1%, 2%, 5% and 10% of full span

Note: Delay unit : FAST - 0.1s, MED - 0.2s and SLOW - 0.5s.

Additional advantages can be gained from the microcontroller-based set-up. Through an on-board RS232C port in the simulator, automatic data logging can be easily provided on any personal computer (PC). Self documentation is easily provided as the PC can read the status of all the various process parameters and switches selected by the user. Yet another feature is that the PC can by-pass the simulator front-panel and download the values and status of all the process parameters and switches. It is thus possible to write an application software on the PC to generate a sequence of process conditions to facilitate testing of the controller accordingly [8]. This effectively yields an automated benchmarking procedure for evaluating the various features of advanced controllers. It is also feasible to have user-selected process modules, such as that representing a simplified distillation column, stored in the PC and then downloaded to the simulator when requested.

EXAMPLES

Evaluation of auto-tuning and self-tuning PID controllers

Almost all the major control system suppliers are now offering auto-tuning and self-tuning single-loop PID controllers. Owing to patent restrictions, they have to be modified or based on entirely different principles such as pattern recognition, relay feedback, correlation, system identification, etc. Their performances may be very different although all these suppliers claim superiority of their products [9],[10]. Hang and Sin [8] have therefore suggested a comprehensive comparative bench-marking testing of these controllers using the microcontroller-based process simulator. Typical results showing the large difference in performance are given in Fig. 4.

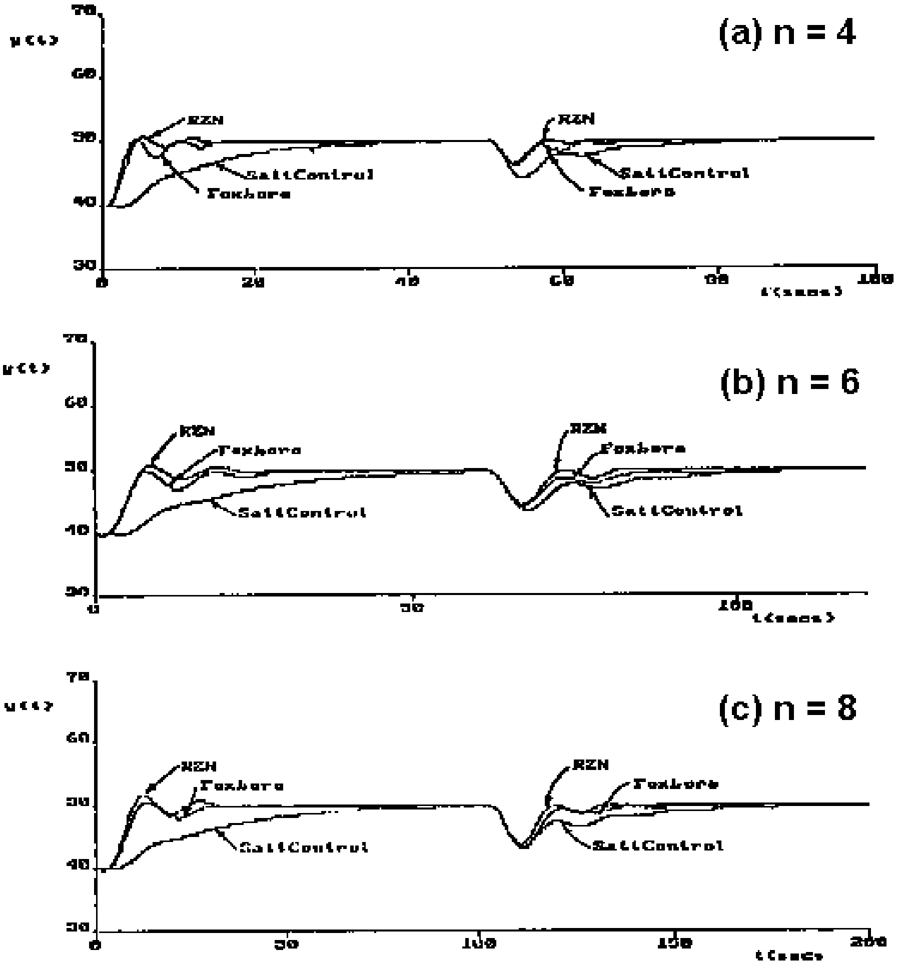

Figure 4 A comparative performance test of three controllers using the process simulator

Even for the same self-tuning controller, there are many adaptation properties that the engineer or operator should learn about. For instance, the PID parameters tuned for optimal setpoint response may not give a sluggish load disturbance response and vice-versa, that tuned for optimal load response may give a very oscillatory setpoint response. This is clearly demonstrated in Fig. 5. At t = 0 with an initial set of PID parameters, a setpoint change was made to the Foxboro EXACT self-tuning controller and a new set of PID parameters (optimal for setpoint changes) was resultant. When a load change was experienced later, the response was very sluggish, this resulted in a new set of parameters. After another load change, a set of parameters optimal for load changes was concluded. When a setpoint change is then requested, a response with large overshoot is resultant. [Note : This problem cannot be resolved unless the controller has two degrees of freedom or has a setpoint weighting feature [8].]

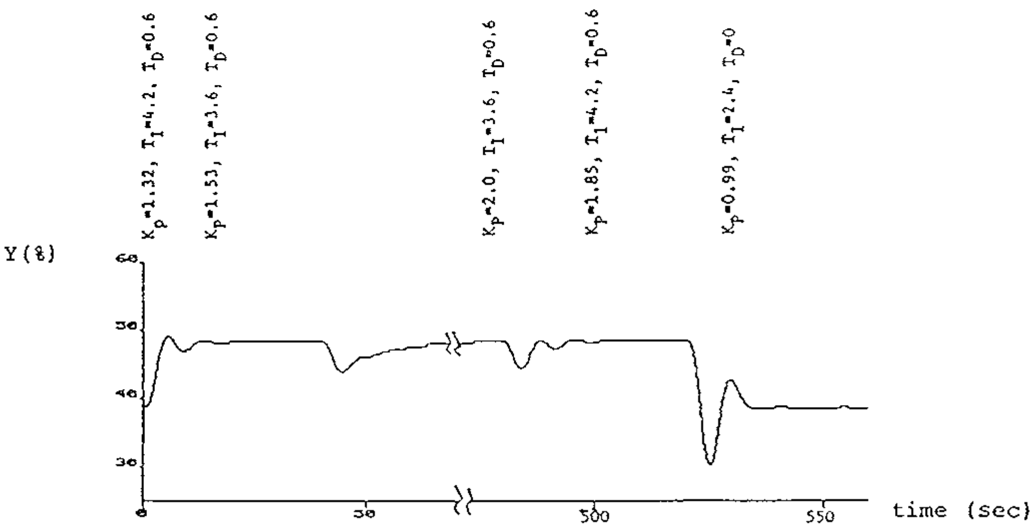

Figure 5 Difference in optimal setpoint and load responses (Process : $1/(1+s)^4$)

Another feature of most self-tuning controllers is that the process dead-time must be known in advance or computed on-line. It is thus important to examine whether a commercial self-tuning controller is robust to changes in dead-time. Such a test is shown in Fig. 6 which shows that the Foxboro EXACT controller is able to cope with large changes in process dead-time after one transient.

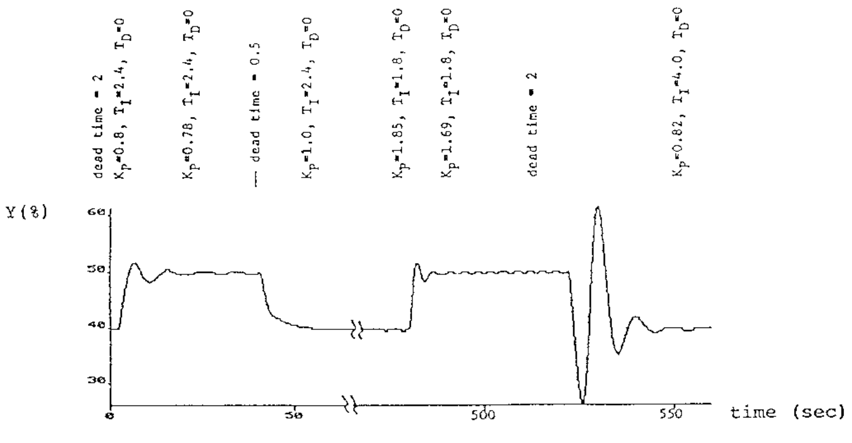

Figure 6 Effect of dead-time changes (Process : $e^{-ds}/(1+s)^2$)

Nonlinear Control

The microcontroller-based process simulator is most ideal for training in the use of single-station microprocessor-based controller which has many new features of advanced control. In this section, the use of "gain-scheduling" PID auto-tuning controller to overcome process non-linearity is demonstrated.

The process to be chosen has a dead time of 1 sec and four lags of 1 sec each. A nonlinear gain element is chosen. Without gain scheduling, the PID controller is tuned at the setpoint of 50% and the performance, as shown in Fig. 7 is good. But when the setpoint is adjusted to 10%, the control performance becomes very sluggish and unacceptable. Using the "gain scheduling (GS)" feature, the controller is tuned at both 10% and 50% using the actuator signal as the GS reference and the optimal tuning parameters are automatically memorised by the controller. As shown in Fig. 7, the control performance (shown by the solid graph) is vastly improved with gain scheduling as the controller settings are automatically changed as the reference variable changes.

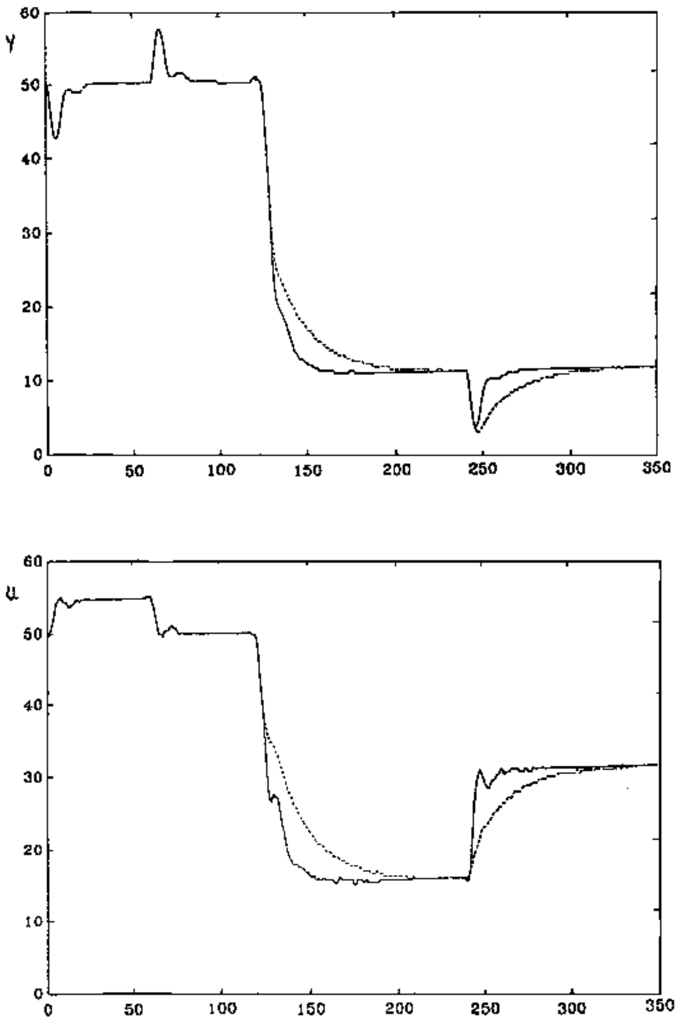

Figure 7 Nonlinear control (----- without gain scheduling; ___ with gain scheduling)

CONCLUSIONS

The conventional methods of providing training to engineers and operators in the use of advanced control are either expensive or time-consuming to set up. A microcontroller-based process simulator has been introduced in this report to address this problem. It is simple to use and its cost is much lower than that of an analogue computer-based simulator. It is portable and is most suitable for the evaluation and training in the use of microprocessor-based single-station controller which has many new features of advanced control. It should appeal greatly to vendors, end-users, academic institutions and research centres.

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