A Course on

THE INTEGRATION OF REAL-TIME COMPUTING INTO PROCESS CONTROL TEACHING

PART I: THE GRADUATE COURSE

M. MORARI and W. H. RAY
University of Wisconsin
Madison, Wisconsin 53706

THE PROCESS CONTROL curriculum at Wisconsin presently involves two faculty members and consists of an undergraduate course (annual enrollment ~80 students), a graduate course (enrollment ~20 students), and an informal graduate research seminar. This paper will concentrate on a description of the graduate course. An overview of the undergraduate course will follow in the next issue of this journal. **The objective of the course is twofold: 1) to familiarize the students with those classical and modern results of process control theory which have been found useful in practical applications and 2) to allow the student to gain experience in the implementation of these techniques via a real-time computer. Therefore the course includes a laboratory.** It is stressed to the students that the computer is simply a modern tool so that the discussion of hardware aspects and specific programming techniques is limited to only those subjects of importance to the process control engineer. Software has been developed so that almost all of the real-time programming done by the students is in FORTRAN IV.

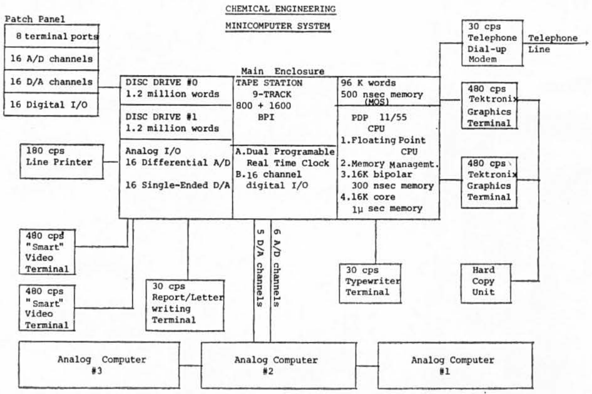


Figure 1
CHEMICAL ENGINEERING
MINICOMPUTER SYSTEM

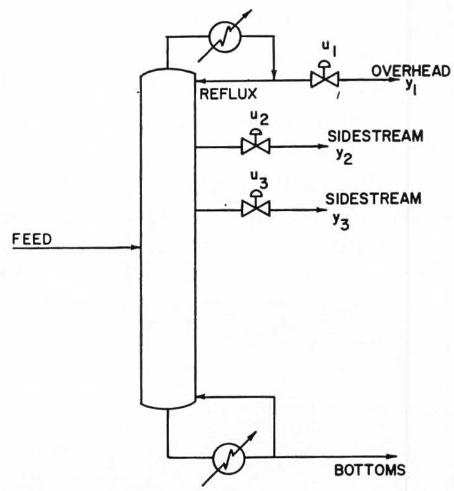


FIGURE 2. Multi-sidestream Distillation Column with Draw-off Rate used to Control Sidestream Composition.

THE COMPUTING FACILITIES

THE COMPUTING FACILITIES for the process control laboratory consist of both analog and digital computers. There are three ±100 volt analog computers with a total capacity of 132 amplifiers used primarily for process simulation. The digital computer available for the laboratory is a PDP11/55 minicomputer operating under the RSX11M operating system. The configuration, shown in Figure 1, includes 128 K words of

TABLE 1

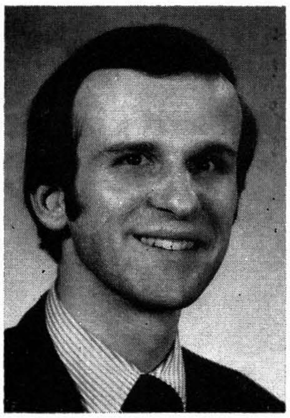
Graduate Process Control Lecture Topics

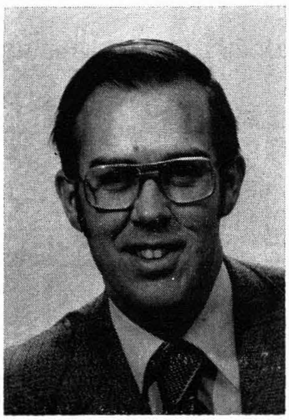
1. **Practical aspects of on-line data acquisition and control**
2. **Control of systems described by ordinary differential and difference equations**
3. **Control of systems described by partial differential equations**
4. **State estimation and stochastic control**
5. **Parameter estimation and adaptive control**
6. **Influence of process design structure on process dynamics and control**
7. **Control of interconnected systems of large dimension**

memory, twin 1.2 magaword disks, a 9-track magnetic tape unit, and graphics terminals. There are digital and analog links to each of the laboratories as well as analog links to the analog computer allowing hybrid computation. Analog to digital and digital to analog conversion are done at the computer with 16 channel, 12 bit converters.

COURSE DESCRIPTION

THE GRADUATE PROCESS control course, offered once each year, has attracted students from a wide range of research areas and backgrounds. The course consists of three hours of lecture each week plus a project-oriented laboratory with individually arranged hours. The topics to be covered are selected from those shown in Table 1 and are designed to acquaint the student with the wealth of powerful estimation and control techniques resulting from modern control theory. The emphasis is on algorithms likely to find wide applications in the process industries. Applications and case studies are stressed more than mathematically rigorous derivations. Many homework problems involve computer simulation and the development of control laws either through numerical techniques or using interactive graphical design methods. Much of the lecture material is available in a forthcoming textbook (W. H. Ray, "Advanced Process Control," McGraw-Hill (1980)). A large library of computer programs for the design of control systems has been developed and is readily available to the student. Those programs carry out the numerical calculations necessary to determine the controller or estimator gains, compute the realization of a transfer function or find the needed compensator for interacting multivariable systems. Some well known graphical methods for the design of multivariable controllers (inverse Nyquist array, characteristic loci, etc.) are also available.





Manfred Morari was born in Graz, Austria on May 13, 1951. He obtained his undergraduate education in chemical engineering at the Swiss Federal Institute of Technology (ETH), Zurich. After his diploma he started graduate school at the University of Minnesota in 1975. Upon completion of his doctorate he joined the ChE faculty at the University of Wisconsin in 1977 where he is currently assistant professor. Last summer he worked for Exxon Research and Engineering Company. His research interests include a variety of topics from the areas of process synthesis and process control: synthesis of separation sequences, optimal measurement selection and inferential control, optimizing control and the dynamics and control of large integrated processing systems. **(L)**

W. Harmon Ray was born in Washington, D.C., on April 4, 1940. He received the B.A. and B.S. Ch.E. degrees from Rice University, Houston, Texas, in 1962 and 1963 respectively, and the Ph.D. degree in ChE from the University of Minnesota in 1966. He has been on the faculty of the University of Waterloo in Canada (1966-70), the State University of New York at Buffalo (1970-76), and the University of Wisconsin, Madison, where he is presently Professor of ChE. During the 1973-74 academic year, he was on sabbatical leave as a Guggenheim Fellow in Belgium and Germany. His research interests include chemical reactor engineering and process modelling, optimization, and control. His publications include an edited volume "Distributed Parameter Systems" (Dekker, 1977), and two monographs "Process Optimization" (Wiley, 1973) and "Advanced Process Control" to be published by McGraw-Hill in 1980. **(R)**

TABLE 2
Some Recent Graduate Laboratory Projects

1. Multivariable computer control of a multi-side-stream distillation column
2. State estimation and stochastic feedback control of a nonisothermal continuous stirred tank reactor
3. On-line parameter identification for a reactor having catalyst deactivation
4. State estimation and stochastic feedback control of interacting gas storage tanks
5. On-line parameter identification for a steel ingot in a three zone furnace
6. Implementation of the Self Tuning Regulator for level control with widely varying process gains and time constants
7. Control of thermally coupled distillation columns
8. Control structures for heat exchanger networks

The principal part of the laboratory activity is devoted to a rather substantial term project over which a formal oral and written report is made. Most of these projects are carried out by two students working together as a team. The topics and the emphasis of the projects vary from year to year. The titles of some projects recently completed are listed in Table 2. Some of them (1, 2, 3) involve hybrid computation where the process is simulated on one of the analog computers and the control algorithm is realized on the digital computer. Others (4, 5, 6) deal with the testing of algorithms on actual physical processes which are completely interfaced with the minicomputer for data acquisition and control. A third category (7, 8) is mostly computational in nature and has as its goal the investigation of the process design-process control interactions.

As an illustration, one such recent project involved the control of side stream compositions via draw-off rate adjustment for a multi-side-stream distillation column (Fig. 2). This is a multivariable control problem for a system having strong interactions. The column was simulated on the analog computer and a variety of feedback control schemes ranging from classic single loop

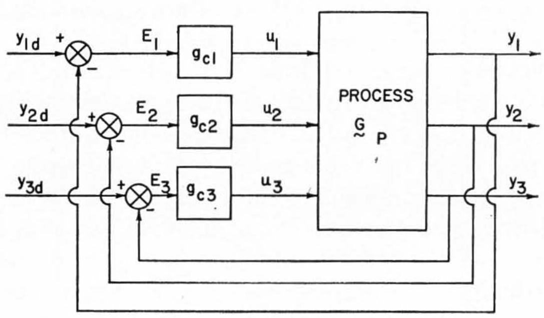


FIGURE 3. Multiple Single-loop Control.

control to optimal control were implemented on the digital computer and their performance evaluated. Multiple PI single loop control, shown in Figure 3, leads to strong oscillations and long settling times (Figure 4) and was therefore not acceptable. However, the implementation of a non-interacting control scheme, for example, using a dynamic compensator as shown in Figure 5 resulted in much improved controller response (Figure 6).

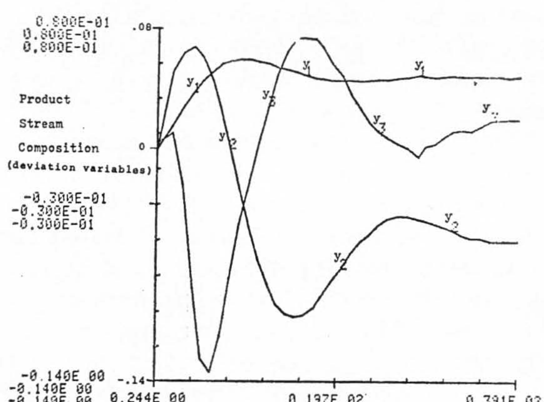


FIGURE 4. Product compositions for multiple-single loop PI control.

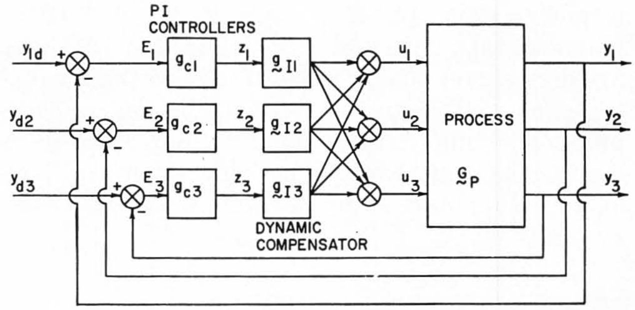


FIGURE 5. Non-interacting Multivariable Feedback Control.

Through projects such as this one,* the students learn the specific advantages and pitfalls of the various control algorithms and are able to see clearly how actual implementation may be carried out in practice.

CONCLUDING REMARKS

As with any curriculum, the offerings in process control at Wisconsin will change and evolve with time. In addition to modifications in the lecture material, we are constantly altering

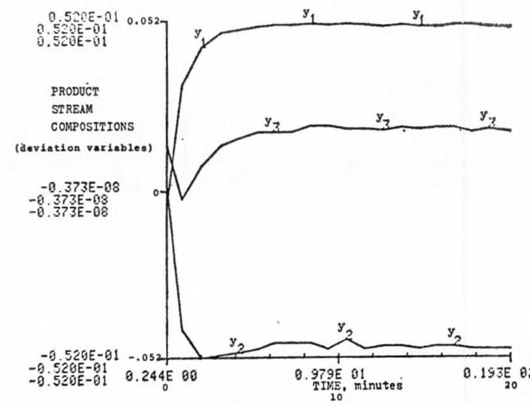


FIGURE 6. Product compositions under dynamic non-interactive control.

the mix of laboratory projects in the graduate course. Often experiments are developed in the graduate course as special projects and subsequently included in the regular curriculum of the undergraduate course. These revisions arise partly in response to student comments and suggestions, but mainly are the result of better perceptions of the best integration of theory and experiment in teaching process control. □

*This project was carried out by graduate students, Lance Lauerhass and Paul Noble. Lance recently has completed his thesis on process design strategies while Paul is doing thesis research in bioengineering.