UNDERGRADUATE PROCESS CONTROL

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PROCESS CONTROL HAS become a subject of more importance in recent years because of two major trends. The first trend is that increased energy conservation, more stringent environmental standards, and tougher economic competition have forced industry to use more complex processes than in the past. These processes are more difficult to control, yet control requirements have also increased since processes often operate near process limits. The second trend is that rapid increases in computing power and rapid decreases in computing cost have made feasible more complex control strategies. The result is the need for more training in process control at the undergraduate level for all engineers rather than only for those with special interests or career goals in process control. Recognizing this, the chemical engineering faculty at Auburn University doubled the process control course requirements during a recent study and revision of the total undergraduate curriculum. The 1985 class was the second class to graduate under the revised curriculum. We would like to describe our experiences in the process control sequence.

Some background information should be provided first. Our undergraduate enrollment has followed national trends, with the graduating class being approximately 25 ten years ago, 90 two years ago, and 70 in 1985. Typically, 85-90% of the graduates take industrial positions. The entering freshman class in 1985 had an average composite ACT score of approximately 26.

The process control sequence consists of two four-credit hour lecture courses taken in the first two quarters of the senior year and a two-credit hour laboratory course which may be taken in either the second or third quarter. The chemical engineering prerequisites include courses in material and energy balances, thermodynamics, fluid mechanics, heat and mass transfer, stagewise processes, reactor engineering, and unit operations laboratory.

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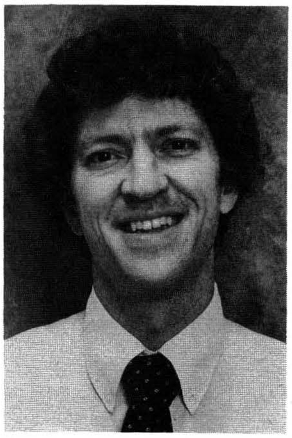
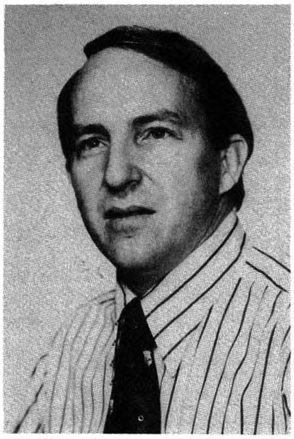
LECTURE COURSES

The text is *Chemical Process Control* by Stephanopoulos [1]. The first course covers Introduction to Process Control (2 lecture hours, Ch. 1-3): motivation for control, control hardware; Mathematical Modelling (12, Ch. 4-9): art of modelling, linearization, deviation variables, Laplace transforms, transfer function models; Dynamics of Linear, Single Variable Processes (6, Ch. 10-12): first order processes, second order processes, higher order processes, dead time, inverse response; and Analysis and Design of Feedback Control Systems (13, Ch. 13-18): PID control, stability analysis, controller tuning, and frequency response analysis. The second course covers Digital Control (16, Ch. 26-30): hardware, samplers and holds, z-transforms, pulse transfer functions, stability analysis, position and velocity PID algorithms, design of algorithms for specified response including deadbeat control and Dahlin's algorithm; Advanced Topics in Single Variable Control (6, Ch. 19-21): dead time compensation, inverse response compensation, cascade control, selective control, split-range control, feedforward control, ratio control; Multivariable System Control (8, Ch. 23-24): selection of control inputs and outputs, interaction analysis, decoupling control; and Other Topics (5, not in text): control valve characteristics and sizing, P&I diagrams. The text is followed closely with occasional omission of a topic, *e.g.*, root locus, and the occasional addition of a topic not in the text, *e.g.*, the Shannon sampling theorem and aliasing of sampled periodic signals. The last topics covered in the second course are the only major exceptions to following the text closely. The level of coverage of control valve characteristics and sizing is more like that of Smith and Corripio [2], and manufacturer's literature is used for some homework problems. P&I diagrams are taught by examples donated by various industries. A useful reference here is Warren [3,4].





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The teaching style is traditional. The lecture over the quarter averages to be half spent on lecturing on new material and half spent on reviewing assigned problems. One or two homework problems are assigned each class and collected at the next class. Some computer programs have been written by the instructors for aiding on homework, *e.g.*, calculation of frequency response from a transfer function. Occasionally, computer programs written by the instructors have been used as the basis for a lengthier homework assignment. This has been done more commonly in the laboratory course and is described in more detail below.

LABORATORY

In the laboratory course five or six experiments are performed. The experiment sequence is model identification, controller and instrument calibration, and controller tuning, with two experiments in each category being typical, although there is wide variation. The students work in groups of three or four. For each experiment there is a conference prior to the experiment where the experiment objectives, procedures, and theory are explained. For each experiment the group makes a written and an oral report. The requirements for the written report normally are specified and involve only specific calculations, *e.g.*, determining a transfer function. The oral report covers the group's interpretation and evaluation of the results of the written report. The group must also justify the computation methods and assumptions made in preparing the written report. The most satisfactory schedule has the pre-experiment conference on Wednesday, the experiment on Thursday or Friday, the written report due on Monday or Tuesday, and the oral report on Wednesday. Unfortunately, due to other schedule constraints we have not been able to maintain this schedule every quarter.

Both digital control and pneumatic analog control are used. The analog controlled processes include level control of a single tank, level control of two tanks in series, and temperature control of a tank heated by steam injection. The digitally controlled processes include level control of two tanks in series either interacting or non-interacting, temperature control of an oil reprocessing facility, multivariable pressure and flow control of two air storage tanks in series, and multivariable temperature and level control of a stirred tank. Two additional equipment items are being added for next year: packed distillation column control and temperature control of two stirred tanks in series with a variable time delay.

The CRISP control system from Anaconda Advanced Technology of Columbus, Ohio, is used to control most of the digitally controlled processes. This is an off-the-shelf system based on a PDP 11/23 and featuring three high resolution, eight-color CRT operator stations. This provides the students with experience on the type of system now commonly being installed in industry. The oil reprocessing facility is controlled by a Texas Instruments PM550 system. The distillation column is interfaced with a MACSYM 2 from Analog Devices of Norwood, Massachusetts.

In addition to experiments performed in the laboratory, computer experiments have also been assigned. As an example, a program was written to simulate the digital PI concentration and level control of a blending process. The students were asked to tune the controllers with one loop open, close both loops, and compare the control with control obtained with a decoupling controller, which they also were asked to tune.

OBSERVATIONS

As a result of two years of experience with the sequence, we have made several observations. Some of these are specific to the control courses, but others are more general and apply to other courses as well.

The students are better prepared in process control than under the previous curriculum, which had one required lecture course and a one credit hour laboratory course. Whether they are sufficiently prepared is open to question. Our observation is that the control

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of multivariable processes is not that well understood by many students. The exposure to control equipment is too limited, although this is an area more easily remedied on the job. Some concepts such as adaptive control, optimization, and filtering have not even been mentioned. Perhaps these are unnecessary for the BS chemical engineer, but as these concepts become more widespread as in Dynamic Matrix Control or the new expert systems from vendors, the engineer who does not understand how the process is being controlled will be at a disadvantage.

The course is extremely fast paced from the students' perspective. Many of the students have commented that for them these are the hardest courses in the curriculum. This implies that the topics mentioned above as being incompletely covered or omitted can not be included unless the course is expanded or some currently covered material is deleted.

The mathematics obscures the engineering for many students. Our students take four quarters of calculus and a three credit hour course in ordinary differential equations. In the course, as it is now taught, the students must learn Laplace transforms, difference equations, and z-transforms. They must make a large effort to become proficient with these techniques, yet in doing so, they have learned nothing about control. They have generally not had linear algebra, statistics, or optimization. The lack of linear algebra makes work on multivariable systems particularly difficult.

In a course with such a fast pace the text or distributed class notes must be followed. In 1984, the first course text was Coughanowr and Koppel [5], and the second course text was Palm [6]. The material in Palm was not in the order taught and was intermingled with material which was not covered. Since the material in class was presented more quickly than most students could follow, they had to rely on study of the text. With the material scattered many students were unable to learn from the text. This implies that if the course is changed and no suitable text can be found, the instructor must prepare and distribute class notes on the level of a text for those sections of the course not covered by the text.

Students often do not apply their engineering knowledge and rely on brute force to solve problems based on computer simulation. In the blending problem described above, the students were told to use any method they chose to tune the controllers. The only hint given was that simply guessing controller parameters until the simulation showed the desired response was probably a poor way to solve the problem. Despite this hint, that method was chosen by all students, even though the problem was essentially identical with "pencil and paper" homework problems worked in the first course. Since use of simulation packages is becoming more common in industry, it is important to train students to use such tools properly.

The beginning section of the first course on mathematical modelling is very beneficial as an integration of the sophomore and junior courses. There is some discussion on modelling in general, but primarily this time is spent assigning and reviewing problems similar to those worked in earlier courses. The two key differences from earlier courses are that nothing is steady state and that students can not rely upon "this is the heat transfer course, so this must be a heat transfer problem" thinking. It is initially discouraging for students to find themselves unable to work problems they felt they had previouly mastered, but this begins the process of unifying the previously compartmentalized knowledge of courses into a whole body of chemical engineering knowledge.

The laboratory helps the students' understanding of the lecture material. Of course, this should be true of any laboratory course, but it is particularly beneficial here because the lecture courses seem so abstract. Ideally, the laboratory should be split into two one-credit hour courses accompanying the lecture courses, but this is impossible for us with our current enrollments and laboratory space.

The laboratory reporting method is popular with the students and the instructors. The instructor does all the grading and conducts all the oral reports. This is very time intensive, but it provides excellent feedback on student understanding. The written report requirements are kept to a minimum, but we have the freedom to do this because the written report requirements in other required courses are extensive.

SUMMARY

We feel the process control sequence is valuable as a requirement for all undergraduates. Although the courses are difficult, most students feel the material is valuable. We have received only a few comments from former students about the value of the courses, but they have been favorable. With the rapid changes in technology the contents of the course may need revision, but the amount of time devoted to process control will not decrease.

REFERENCES

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2. Smith, Carlos A., and Armando B. Corripio, *Principles and Practice of Automatic Process Control*, John Wiley and Sons, New York, 1985
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5. Coughanowr, Donald R., and Lowell B. Koppel, *Process Systems Analysis and Control*, McGraw-Hill, New York, 1965
6. Palm, William J., III, *Modeling, Analysis, and Control of Dynamic Systems*, John Wiley and Sons, New York, 1983 □

ChE stirred pots

LACEY LECTURESHIP

The tradition of honoring the recipient of the Lacey Lectureship Award each year with a poem tailored to that recipient's particular interests continues at CalTech. The latest tribute was written by Professor R. A. Aris and recognizes in verse the Nineteenth Annual William N. Laey Lecturer, Tom Hanratty.

(UNTITLED)

(With apologies to George Gordon Lord Byron)

He talks of transport like a night
Of boist'rous wind and stormy skies,
Of mass that's moved from left to right
By D_js and v_is,
Enhanced by eddies, loose or tight,
Which laminated flow denies.

One whorl the more, one turb the less
Had half impaired the transfer rate
Which 'stricted eddies would repress
In space which walls delineate,
Where Navier and Stokes express
How swift, how soon they dissipate.

So from the Shell Distinguished Chair
To Lacey's campus near the sea
Rings out the challenge, fair & square:
What shall th'interpretation be
Of matters physical transfer?
Sincerely yours, Tom Hanrattee.

R. A. Aris

ChE letters

COMPUTER COMPULSION?

Dear Editor:

The articles of Professors Luss and Denn in one issue (Winter 1986) indicate the width of knowledge our society would wish to expect of chemical engineering graduates. While it is important that a chemical engineer involved *e.g.* with reactors should be equally conversant with spreadsheets, the FORTRAN/PASCAL/C languages *and* with multiple steady states/bifurcations, our current (and perhaps inordinate) enrapture with computing devices threatens to relegate the latter *i.e.* analytical thinking and a clear understanding of fundamentals, to second place. We will doubtless form one day a mature attitude towards this fast and powerful machinery, but until then, we must insist relentlessly that our students acquire a balanced view of what computers can and cannot offer.

Sincerely,
T. Z. Fahidy
University of Waterloo

ChE book reviews

LIQUIDS AND LIQUID MIXTURES, 3rd Edition

By J. S. Rowlinson and F. L. Swinton
Butterworths, London, 1982. $69.95

Reviewed by
Keith E. Gubbins
Cornell University

Thirteen years have elapsed between the appearance of the second and this, the third, edition of this authoritative monograph on liquids and liquid mixtures. In that time much has happened in both the experimental and theoretical aspects of the subject. Many new and more accurate measurements of ther-

Continued on page 83.