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Book Reviews

MULTIVARIABLE COMPUTER CONTROL — A CASE STUDY, D. G. Fisher and D. E. Seborg, North Holland Publishing Company, 1976.

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The book *Multivariable Computer Control—A Case Study* is a compilation of articles previously authored by D. G. Fisher and D. E. Seborg between 1972 and 1974 describing work done on computer control projects in the Department of Chemical Engineering at the University of Alberta. The articles discuss multivariable design, analysis, and control techniques and their implementation on a pilot scale double effect evaporator, and are divided into seven sections. Each section is preceded by a short editorial review of the articles following.

As discussed by the authors in the Preface, the evaporator is not necessarily the most appropriate piece of equipment for evaluating advanced control techniques. It is simple enough to be modeled from first principles (material and energy balances) yet complicated enough to warrant process identification; process interactions justify a multivariable control approach. The evaporator is highly instrumented (more so than the industrial norm), thus providing a well-designed experiment which facilitates data interpretation and evaluation of various control methods. The case study is not intended to be a textbook on control (although there are some tutorial articles included) but rather a convenient collection of articles to illustrate control applications. This series of studies by Fisher, Seborg, et al. is the most comprehensive investigation of its type in chemical process control. Prior to 1978, applications of modern control theory were limited to pilot scale installations. However, with increasing energy conservation efforts in the process industries, the commercial acceptance of such techniques as multivariable control has become a reality. Thus Fisher and Seborg's papers are largely still relevant ten years later.

The first section is an overview of multivariable techniques and discusses improvements in performance over conventional techniques as well as their potential for industrial application. Section two contains four articles on modeling and simulation, since implementation of advanced control techniques requires a mathematical model of the process. The first article considers approaches for modeling of evaporators and the use of these models in controller design. The second article describes a program package (GEMSCOPE) for dynamic systems. The evaporator model can be expressed as a tenth order nonlinear system; using different physical assumptions, a fifth order model can be derived. The third article considers model reduction by the extension of the continuous time methods of Marshall and Davison to discrete time, simplifying the evaporator model to second and third order. The fourth article deals with hybrid simulation and describes the use of analog computers for the simulation of an evaporator and its use in evaluating multivariable control schemes.

Section three deals with conventional computer control. The implementation of direct digital control on a pilot plant evaporator is discussed. The control laws considered are discrete PI, feedforward, and inferential. State estimation and filtering techniques are also considered. Section four presents techniques for designing discrete time-invariant multivariable controllers. In the first article, a quadratic performance index is used in the design of a multivariable controller. Implementation of the controller requires the use of state estimation. The modifications for including integral action, feedforward control, and model following capabilities are also considered. The second article discusses the application of multivariable feedforward algorithms for the control of measured disturbances. In the third article, the modal approach to control law reduction is examined. Here, an optimal controller is designed for a linearized high order process model which utilizes the entire state vector. Then, using modal analysis, the control law is simplified by eliminating selected state variables from the state feedback control law. Thus, a reduced order control law is obtained. The fourth article compares two approaches for designing reduced order control laws. In the first approach, the high order model is reduced and the controller is designed for the low order model. In the second approach, the controller is designed for the high order model and then the resulting high order control law is reduced. The latter method was found to perform better experimentally.

The fifth section contains two articles dealing with multivariable servo control. Here, a minimum time performance criteria is used in the design and the resulting discrete optimal control policy is calculated a priori. Considerations for application of such a controller are modeling errors, process noise, nonlinearities, and unmeasured disturbances. Section six considers multivariable adaptive controllers and multivariable dead time compensators. The first two articles are about multivariable model reference adaptive control. With the model reference approach, the control law is adjusted so that the process response follows the response of the process model. The Liapunov stability theorem is used to design the controller adaptation law. The drawback to this technique is that when the number of control variables is less than the number of states, which often occurs, the stability of the controller adaptation law cannot be guaranteed. The results from hybrid simulation and ex-

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perimental application to the evaporator are also included. The third and fourth articles present the extension of the Smith Predictor to multivariable linear systems containing time delays. The limitation to this technique is that the delays must be the same for all variables, which does not seem very realistic. Recently a more comprehensive multivariable dead time compensator has been developed by H. Ray at Wisconsin. Simulation studies and applications to the evaporator are also presented.

The seventh section deals with on-line estimation and filtering. Many control laws require the entire state vector when not all the states are measurable. This requires the use of state estimators such as the Kalman filter and Luenberger observer which are discussed here. The first article evaluates the Kalman filter in simulation and experimental studies on the evaporator. The Kalman filter was implemented with an optimal multivariable feedback controller and the effects of design parameters, errors in the model parameters, and incorrect process statistics on the performance of the filter are examined. Satisfactory state estimates were obtained even in the presence of significant noise levels, uncertain noise statistics, and significant modeling errors. However, the filter was found to be sensitive to unmeasured step disturbances entering the process. The second article compares the Kalman filter and Luenberger observer for providing state estimates to an optimal feedback control system applied to the evaporator. The Kalman filter, which is designed for stochastic processes, gave satisfactory results with noise, uncertain noise statistics, and modeling errors, but it was sensitive to unmeasured disturbances. The Luenberger observer, which is designed for deterministic systems, was quite sensitive to process noise and unmeasured disturbances. Thus, the Kalman filter is a better choice for process control applications.

The final section is on the educational aspects of computer control and provides a description of the real time computing facilities at the University of Alberta.