Wen-Jei Yang and Masami Masubuchi

# DYNAMICS OF PROCESSES AND CONTROL SYSTEMS*

Reviewed by I. Maslennikov

The book reviewed here is a reprint of lectures on the dynamics of process control in heating liquids, which Wen-Jei Jang had delivered at the University of Michigan, and on the theoretical principles of automatic control and optimal regulation, which Masami Masabuchi had delivered at the National University in Yokohama.

In the foreword the authors correctly emphasize the importance of research in process dynamics and the necessity of combining the analysis of transfer phenomena with the principles of automatic control. Not without justification is also the authors' remark that most often physical systems are treated as systems with lumped parameters and that solutions are usually obtained by the method of Laplace transforms, while in fact all physical systems are characterized by a distribution of parameters and other methods of solving problems are available. One cannot agree, however, that the authors are the first ones to have dealt with the dynamic characteristics of regulation plants and to have outlined the principles of designing regulation systems, the first ones to have analyzed the physical nature of mass and heat transfer processes, or the first ones to have used the methods of states space in the control theory.

Obviously, they should have properly evaluated earlier publications where, along with the dynamic characteristics necessary for the synthesis of control systems, also the physical nature of heat and mass transfer was revealed as, for example, in "Process Dynamics" by Donald Campbell (1958). They should also have mentioned earlier studies where not the classical theory of regulation in conjunction with Laplace transformation and the Z-transformation was used but the "modern" theory which draws on the methods of state space and a system design reduced, essentially, to extremizing a functional. Here belongs the book "Modern Control Theory" by Professor Julius Ty of the Northwestern University in the USA, published in 1964. It is noteworthy that Prof. J. Ty, when speaking about the concept of state space, says: "This approach to solving problems in automatic control was laid down first during the nineteen forties by the Russian scientists M. A. Aizerman, A. A. Fel'dbaum, A. M. Letov, et al." In 1965 Paul M. DeRusso, Robert G. Roy, and Charles M. Glaus wrote a book for engineers under the title: "State Variables for Engineers," entirely devoted to the application of the state space and the control theory. It is written there: "The intensive developments in the theory of feedback control are to be credited to Lyapunov's work on the theory of stability, to the modern theory of optimization developed by Bellman and Pontryagin, to the works by Kalman, LaSalle, Meriam, et al. All these works are based on the approach from the "state variables" point of view."

At the beginning of Chapter One the authors not very clearly and not very convincingly explain the need for automatic control. They should have compared the operation of enterprises in various industries prior to and after introduction of automatic control. The difference between manual and automatic control is then illustrated on common examples. Here again the authors emphasize very correctly that a study and understanding of the process dynamics is necessary not only for the development of automatic regulation systems but also in many other fields of science and engineering, and that it requires an understanding of the transfer phenomena.

Next the authors show practical applications of automatic control in various branches of technology, including the control of the microclimate in a space ship and the control of nuclear reactor power.

*Gordon and Breach, New York (1970).

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 23, No. 1, pp. 175-177, July, 1972.

Chapter Two deals with the fundamentals of transfer and control processes. Presented here are the concepts of input and output variables (coordinates) in a process. Equations which describe the laws of nature are examined and classified for use in obtaining the dynamic characteristics of given control plants. Concepts pertaining to the control space of a system are defined in descriptive terms, the Euler viewpoint and the Lagrange viewpoint are compared leading, respectively, to equations of total and differential mass or energy balance.

All these topics are treated concisely enough and yet quite adequately from the methodical standpoint.

There follows an analysis of dynamic characteristics in the time domain and in the frequency domain along with the methods of their experimental determination, giving only a general picture about them.

The authors' attempt to interpret the experimental methods of determining time and frequency characteristics cannot be taken seriously. They would have done better leaving this subject alone and only referring to it where necessary. They discuss the active methods, but do not mention at all the passive methods of determining both time and frequency characteristics experimentally. The preparation of tests is treated very primitively. On the question of determining the frequency characteristic by generating a sinusoidal function at the system input, for instance, the authors assume that this is achieved with the aid of a cam, a cam driven element (to mean, evidently, the regulating element), and a mechanical or electrical generator. No mention is made of the often encountered need for a regulating element with a profile without which it would be impossible to generate the necessary harmonic oscillations of the very flow on which this regulating element acts.

Nothing is said about the method of determining the frequency characteristics with a square-wave input signal. This mode of input action is convenient precisely because it can be realized manually with remote-control elements of automatic regulators. Moreover, there is no need here for special signal generators, cams, and profiled regulating elements. The authors should have covered the relation between time and frequency characteristics, in view of the fact that the book was written for students.

There follows an evaluation of the role played by dynamic and static characteristics. Examples are shown illustrating the dynamic behavior of a thermocouple and of a U-tube manometer. Exact solutions are obtained here by the classical method of direct integration. In the discussion is included also a heat exchanger of the coaxial tubular design.

At the end of the chapter are given some basic concepts pertaining to control, but is a rather too concise format. The subjects covered here are, essentially, schematic block diagrams and the effect which the location of the roots of the characteristic equation has on the transient process.

In Chapter Three the authors explain various fundamental procedures for dynamic analysis. They begin with a brief but, considering the scope of the book, adequate review of the straight classical method with an integration of the differential equation, with the use of the Laplace transform, with transfer functions, and with frequency characteristics. Unfortunately, very little is said in this part of the chapter about the Duhamel integral and its possible use for determining the response of a linear system to an arbitrary signal, and nothing at all is said about the delta function or the weighing function, on the relation between the delta function and the unit-step function, between the transient response and the weighting function, and between all these functions and the transfer functions.

These items omitted by the authors are no doubt methodologically very important, because they develop our ability to tie together seemingly unrelated facts.

There follows an analysis of dynamic equations by the methods of the state space and by the method of analog simulation. These methods are described here very thoroughly and are illustrated by a sufficient number of examples to be well understood.

Some ideas about numerical methods of analysis are presented at the end of the chapter.

Chapter Four is devoted to the dynamics of systems with lumped parameters. Such systems are defined first, whereupon the status of dynamic equations is discussed in terms of establishing the transfer functions for thermal, hydraulic, and mass-transfer processes describable by ordinary first-order differential equations.

Considered next is the dynamics of series and parallel detector devices (components) in a control system, also of feedback systems as well as systems with many inputs and many outputs. The application of state space and analog simulation methods is demonstrated in each case. The last section of this

chapter brings two illustrative examples, each solved by four different earlier shown methods and the results compared. Such a comparison is methodologically very useful.

Chapter Five is concerned with the dynamics of systems with lumped parameters. Such systems are defined first, whereupon the status of dynamic equations is discussed in terms of establishing the transfer functions for thermal, hydraulic, and mass-transfer processes describable by ordinary first-order differential equations.

Considered next is the dynamics of series and parallel detector devices (components) in a control system, also of feedback systems as well as systems with many inputs and many outputs. The application of state space and analog simulation methods is demonstrated in each case. The last section of this chapter brings two illustrative examples, each solved by four different earlier shown methods and the results compared. Such a comparison is methodologically very useful.

Chapter Five is concerned with the dynamic behavior of systems whose parameters are distributed. Such systems are defined first, whereupon the general procedure for describing the dynamics of such systems analytically is discussed. Using specific examples, the authors thoroughly deal with the problem of determining the dynamic characteristics of many various thermal, hydraulic, and mass-transfer plants (systems). Most attention is paid here to heat exchangers and pipelines. This is the main chapter of the book, it is the longest, and the authors successfully demonstrate here the serious consideration which curricula should be giving to distributed-parameter systems. (Unfortunately, till now the study programs as well as textbooks and manuals have been very deficient in this area.) In this chapter, however, the authors do not devote enough space to the problem concerning the simulation of distributed-parameter systems on analog computers. No consideration is also given to the possibility of separating two components in expressions which characterize the properties of such systems, namely, the component which represents the dynamic characteristics of a lumped mathematical model of the system and the component which reflects the effect of parameter distribution. As is well known, such a separation of two components does in many cases simplify the analysis of distributed-parameter systems.

Chapter Six deals with the dynamics of nonlinear systems. It is too concise and, in essence, offers but a general brief survey of methods used for studying the dynamics of nonlinear systems. Not enough examples are given here which would explain the application of these methods. Nonlinear systems certainly deserve more attention.

Chapter Seven is about systems with time-variable parameters. This subject is sufficiently well covered for a study course. It includes the application of pulse and frequency characteristics, integral transforms, the method of small perturbations, the method of the state space, and the method of analog simulation. The last of these methods is illustrated on problem of a coaxial tubular heat exchanger, with the solution obtained here for the case where the heat carrier velocity varies in time.

Chapter Eight deals with the experimental procedure for determining the dynamic characteristics. The method of direct measurement is applied to the frequency characteristics (with a sinusoidal perturbation signal), considered is also the method of measuring the transient response (to a step perturbation) and the problem of determining the dynamic characteristics in response to input signals of various pulse forms. Information is given about the general principles of analyzing the system dynamics with the aid of random signals. Examples are shown in which plants are analyzed by way of determining their frequency, transient, and pulse response functions. The apparatus for these tests is described. In this chapter the experimental procedure of analysis is treated more specifically than in Chapter Two, but still not a complete picture is presented of the difficulties arising in the preparation of experiments. Without dwelling enough on the methods of test data processing, as should have been done, the authors proceed to evaluate the test results.

In Chapter Nine the authors discuss the necessity of analyzing the dynamics of enterprises totally and, at the same time, they indicate the difficulties arising here and also certain possible simplifying assumptions. The discussion continues with problems involved in analyzing the dynamics of a steam power plant, of a large thermoelectric power station, of a furnace for heating metal ingots before rolling, of an atomic power plant, of hydro plants, of a distillation column, and of chemical reactors. Analytical methods, simulation, and industrial experiments are all assessed. Still not enough is said, however, about the setting up of an experiment and about the processing of test data. On the other hand, test results are extensively evaluated on a comparative basis, in relation to test results obtained by other methods of dynamic analysis.

On the whole, this chapter should be very useful to specialists in many areas, because examples are thoroughly analyzed here which have been taken from various branches of industry.

Chapter Ten is devoted to the basic methods of controlling manufacture processes and to the synthesis of control systems on the basis of process dynamics analysis.

This chapter is too concise and amounts to a general survey. After having read it, a student, nor even an engineer, will be able to design and to properly set up an automatic regulation system. This chapter may be viewed as a not very systematic introduction to a book on problems in the synthesis of automatic regulation systems.

It must be noted, however, that, on the whole, the book is written on a level with modern concepts in the theory of automatic control and it makes use of the available mathematical apparatus. Its value is much enhanced by the great many chosen specific examples. The authors are unquestionably very competent specialists in the field of automatic control. Despite the deficiencies mentioned here, the book will certainly be useful to students and engineers working on problems in the automatic control of manufacture processes.