Studies in process control, reliability engineering, loss prevention and plant engineering

STUDIES IN PROCESS CONTROL, RELIABILITY ENGINEERING, LOSS PREVENTION AND PLANT ENGINEERING

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CONTENTS

INTRODUCTION

The common theme of the work is the design and operation of chemical plant in the face of disturbances and failures.

The early work is concerned with the derivation of unsteady-state models of chemical plant which may be used in the design of control systems and of protective systems. In particular, a number of general methods of simplifying transfer functions and state variable models have been developed.

This has been followed by work on computer control of plants, particularly direct digital control (ddc). One aspect emphasised is the analysis of process characteristics and of computer functions in order to exploit the potential of the computer. Another is the measures necessary in order to achieve high reliability and availability in ddc.

In the work on computer control the overall objective set has been to try to identify and solve the problems which would have to be solved for the achievement of unmanned operation, not necessarily for its own sake but as a spur to the development of the technology. This has led to work in two further fields.

One of these fields is the control of plants by the process operator, particularly in computer controlled systems. Two books (Publs 26 and 27) have been published on this topic. The other field is the handling of fault conditions by the computer, particularly malfunction detection. These two themes have been developed separately but in addition they come together in the work on alarm systems and alarm analysis and on human error.

The work on malfunction detection has concentrated particularly on instruments. A survey of instrument failure rates has therefore been done in order to get the measure of the problem. This has then led to further work on instrument reliability.

The work on liquid drying arose from the problem of corrosion due to a wet liquid and has resulted in the development of two unconventional drying methods.

The work on instrument reliability has widened to an interest in the general application of reliability engineering to chemical plants.

This interest in turn extended soon after to cover the much larger field of loss prevention. Here work has been done both in the general area of hazard control at national level , including service on the Advisory Committee on Major Hazards and the writing of a textbook, and on particular topics. Many of the topics already mentioned are relevant here, including reliability engineering, instrument failure, alarm systems, and human error. Other work has been done on trip system reliability and pressure vessel failures.

Reliability engineering was introduced into the undergraduate course in chemical engineering at Loughborough by Professor D. C. Freshwater, Dr. B. A. Buffham and myself. This concern with failures on chemical plants broadened into an interest in the general problems of the plant engineer . This led to my appointment in 1974 to the Chair in Plant Engineering.

Apart from the material already described, work in the plant engineering area has been concentrated primarily on the application of reliability engineering concepts to maintenance problems. This forms only a small proportion of the work submitted, but as leader of the Plant Engineering Group I have general responsibility for the programme of work in this area, which has been undertaken mainly by Mr. R. J. Aird, who is a permanent member of staff and who has carried out a series of studies on the reliability of particular types of equipment (motors, mills, pumps, relief valves) and Dr. D. J. Sherwin, who has been a Research Fellow and who has developed general methods of analysing, operating and modifying maintenance systems.

A more detailed account of the development of these themes in particular publications is given in the next section.

SUMMARY OF PUBLICATIONS

Papers (1) - (17) are concerned with unsteady-state modelling of chemical plant. Papers (1) - (6) deal with the modelling of the unit operations of evaporation and gas absorption. Papers (7) - (16) describe methods for the simplification of unsteady-state models of large linear systems. Paper (17) is on digital simulation.

Paper (1) is a two-part paper containing both theoretical and experimental work on the unsteady-state modelling of a concentrating evaporator and also on its control.

Papers (2) and (3) describe both theoretical and experimental work on the unsteady-state modelling of plate and of packed gas absorption columns, respectively. Papers (4) - (6) treat particular aspects of unsteady-state modelling of gas absorption columns.

Paper (7) describes a method of reducing a complex transfer function model of a linear system to a simple transfer function model by matching the moments of the impulse responses. Previously moments matching had been widely used to fit experimental data to theoretical models. It had also been suggested some years earlier from matching theoretical models, but in the latter case the method presented was difficult to use. Our paper presents a method based on a simple differentiation which makes its use quite straightforward.

Paper (8) shows how the moments required for the method of paper (7) may be obtained directly from the unsteady-state linear model without the need to derive a complex transfer function, thus further extending the utility of the method.

Paper (9) deals with the application of the method to systems with oscillating and inverting responses.

Papers (10) and (11) review the methods available for reducing high order state variable models to simple transfer function models. The main methods are frequency response matching, moments matching and continued fraction expansion.

Paper (12) demonstrates that the moments matching and continued fraction expansion methods are in fact identical.

Papers (13) and (14) describe methods for the reduction of the order of state variable models using moments matching and frequency response matching, respectively.

Papers (15) and (16) treat particular aspects of the model reduction work.

The work on model reduction may be summarised as follows. There are two main types of model: Transfer function (one input/one output) and state variable models (multiple inputs/multiple outputs) and four main methods of model reduction: eigen_value elimination (state variable models only), moments matching, frequency response matching and continued fraction expansion. The contribution of the papers described is thus as follows:

Models	Reduction method			
	Eigen_value elimination	Moments matching	Frequency response matching	Continued fraction expansion
Transfer function	-	Paper 7	-	(Paper 12)
State variable	-	Paper 13	Paper 14	-

Paper (17) describes a simple method of solving an unsteady-state partial differential equation model while retaining its distributed parameter features by the method of characteristics using a digital simulation language. This work arose from the requirement to retain this feature in modelling a cement kiln for computer control.

Papers (18) - (20) deal with process computer control. Paper (18) describes an industrial project on computer control of a cement kiln with particular emphasis on unsteady-state modelling of the kiln, on direct digital control features and on computer reliability and availability. Paper (19) reviews the evaluation and organisation of process computer control projects. Paper (20) reviews in detail the actual functions performed both by a process operator and by a process computer. Further treatment of computer control is given in many of the other publications particularly (21) - (31), (47) and (58) - (64).

Publications (21) - (28) deal with the process operator, particularly in computer controlled plants. Papers (21) - (22) and (23) describe the influence on the operator's role of the process characteristics and of the control system provided, respectively. Paper (24) reviews the problem of information display and paper (25) describes some particular visual displays.

Publication (26) is a book on operator control, computer control and operator - computer interaction. It originated as a report of an Industrial Research Fellowship of the Institution of Chemical Engineering on "Man-Computer Interaction in Process Control", which eventually turned into a book.

The fellowship was held jointly with Dr. Elwyn Edwards, then Reader in Ergonomics at LUT and now Professor in the Department of Applied Psychology, University of Aston. Publication (27) is a collection of classic papers on the process operator which was assembled during the course of this work. Publication (28) is a review of problems in research on the process operator written for the latter volume. To my knowledge these two volumes remain the only books which give a balanced treatment of the process operator and his task, particularly in computer controlled systems, although there are numerous publications on various specific human factors aspects.

Papers (29) - (31) deal with human error in process control. Papers (29) and (30) are reviews which give taxonomies of human error and try to link them with topics in human factors where some data are available. Paper (31) reviews operator response in emergency situations and describes experimental work on a simulator on this problem.

Papers (32) - (36) deal with the drying of organic liquids. The reason for this work is that wet liquids are corrosive and it is often necessary to dry the liquids and so reduce corrosion in order to improve equipment reliability. Papers (32) and (33) describe unconventional methods of drying organic liquids. Papers (34) and (35) describe experimental work on the diffusion coefficient of water in organic liquids, which is anomalous. Paper (36) is a review of problems and methods of liquid drying.

Papers (37) - (44) are concerned with reliability engineering. Paper (37) is a tutorial paper illustrating the application of reliability engineering techniques to chemical industry problems.

Paper (38) gives data on the overall failure rates of instruments in three process plants. To my knowledge this remains the principal published collection of data on instrument failure. It has been widely used in industry, including the Rasmussen Report (WASH-1400) on the safety of U.S. commercial nuclear reactors. Paper (39) gives data on individual failure modes of instruments from the same study. Papers (40) and (41) are reviews of instrument failure data and of the more general problem of instrument reliability, respectively.

Paper (42) gives data on the overall failure rates of pressure vessels in a process plant. To my knowledge this is the first collection of data on failure of process pressure vessels as opposed to pressure vessels in general.

Paper (43) reviews the general problem of data and data sources in reliability work.

Paper (44) is a two-part study of the application of reliability engineering concepts to works maintenance policies and practices. Works failure data

were analysed to detect the failure regime (early, constant or wearout failure) and to provide a rational basis for modification of the maintenance policies. The data analysis was supplemented by observation of the maintenance tasks and detailed investigation of engineering aspects. Two case studies were done, one on a whole chemical plant and one on a set of hospital autoclaves. In both cases early failure due to maintenance inadequacies was a prominent feature and in both cases modifications of the maintenance policies and practices were suggested and implemented. Before and after studies were done to assess the effect of the changes. In the chemical plant the overall equipment failure rate was reduced from 133 to 84 failures per month (Part 2, Table 1) and the unavailability was reduced to 48 - 77% of its original value (Part 2, Table 4). This paper is one of a series on the application of reliability engineering concepts to works maintenance problems, the other papers being written by R. J. Aird and D. J. Sherwin.

Publications (45) - (46) are concerned with loss prevention. Papers (45) and (46) are reviews of the development of the subject.

Publication (47) is a book on loss prevention written primarily as a student textbook. Loss prevention is distinguished by its concern with technological hazards, by its emphasis on formal management systems and procedures, and by its quantitative approach. It is a subject which has developed rapidly in the last 15 years or so and has received considerable impetus from the disasters at Flixborough and Seveso. The importance of teaching loss prevention to chemical engineers has been increasingly recognised and the Institution of Chemical Engineers has been active in promoting this. To my knowledge this volume is the first book which defines the subject area, gives a comprehensive treatment and covers quantitative methods and case histories in detail. Some of the earlier books are given as references in Table 1.1.

Papers (48) -(52) are accounts of developments in the public control of hazardous installations, describing the reports of the Advisory Committee on Major Hazards and the draft Hazardous Installations (Notification and Survey) Regulations 1978. Paper (53) reviews some features of and problems in hazard survey and assessment. Paper (54) is a contribution to the developing system of risk criteria.

Paper (55) describes an approach to the control of hazardous installations in which the principle of diversity and redundancy, which is used so successfully in reliability engineering generally, is applied to the hazard control system itself. The paper also introduces the idea of hazard warning structure, which is developed more fully in paper (56).

Paper (56) describes the concept of hazard warning structure. Quantitative assessments of hazards such as those based on fault trees are often criticised as over-optimistic and liable to omissions. Critics keep returning to the magnitude of the hazard potential . An approach that may help reduce some of these difficulties is to exploit the hazard warning structure of major hazards. The basic idea is that before the worst event, i.e. the fault tree top event, occurs, there will normally be a series of lesser events, i.e. events further down the tree, which can act as warnings. In particular, if these warning events are not occurring, there is good assurance that the worst event will not occur either. The hazard warning structure may be made explicit by developing the fault tree for an installation in a particular way so that it is in effect a hazard warning tree. The principle is that a more severe event is generally the outcome of a less severe event and of the failure of a mitigating feature.

Paper (57) gives an exact treatment of the reliability of a single channel trip system. It is shows that existing expressions for plant hazard rate, trip fractional dead time, etc., are special cases which only apply subject to certain restrictive conditions.

Paper (58) reviews the contribution of the control system to loss prevention.

Papers (59) - (67) deal with operator and computer monitoring of equipment malfunction . Papers (59) and (60) are reviews of the potential of the process computer in this area. Paper (61) describes the ways in which the process operator detects one particular category of malfunctions, those in instruments.

Papers (62) - (65) describe theoretical and experimental work on methods for detection by the process computer of malfunction in its instruments. These methods are applicable to individual instruments or individual control loops and do not involve complex modelling of large

sections of the process. Paper (62) gives a method for malfunction detection in a measuring instrument or a control valve based on the signal noisiness. Paper (63) gives a method for malfunction detection in the instrumentation of a flow control loop (measuring instrument, current/pressure transducer, control valve) based on the relation between the flow and the valve stem position using a simple estimator. Paper (64) gives a method for malfunction detection in the instrumentation of the general control loop, again based on the relation between the variable and the valve stem position, using a Kalman filter. A level control loop was studied as representative of the general loop. In order to do this latter work it was necessary to develop a method of applying Kalman filtering where the noise characteristics of the measurement and system are unknown and this is described in paper (65). These two techniques for detection of malfunction in control loops are subject to some restrictions as described in the papers but otherwise are general methods.

Papers (66) and (67) are concerned with the problem of modifying an a priori estimate of the reliability of a device in the light of information about the current state of that device obtained by monitoring it on the plant.

Papers (68) -(73) are concerned with process plant alarm systems. Paper (68) is a general review of this area which emphasizes that there are major problems in alarm systems and that this is a neglected topic.

Paper (69) - (72) deal with alarm analysis. This is an advanced facility first installed about 1965 on certain nuclear power stations in the UK to assist the operator to handle and to diagnose the alarms. We took the view that this is a useful facility to provide but it would be economic for chemical plants only if a systematic method could be developed for the creation of the necessary data structures. Two methods have in fact been developed. Both are based on representing the plant in terms of a configuration of units and of models of these units. The type of model used is described in papers (69) and (70). Paper (69) describes Method 1, in which the relations between alarms are represented as a loosely structured network of alarmed variables which can (but not necessarily will) affect each other. Paper (70) describes Method 2, in which the relations between the alarms are represented as a more rigidly structured fault tree of the alarmed variables. Paper (71) again describes Method 2 but with greater emphasis on the overall alarm analysis problem. Paper (72) gives a review of these two methods and describes experimental work. Papers (70) to (72) also review the state of the art.

The method of alarm analysis described in papers (70) and (71), is based on a fault tree structure. In effect it constitutes a method of fault tree synthesis which has application in design as well as in process control. Paper (70), (73) and (74) describe the application of the method to fault tree synthesis.

The representation of fault propagation in process plants, whether fault tree synthesis for design or alarm analysis for process control, is in fact a generic problem. This is the theme of paper (75).

Work is currently in hand on a computer-based system for the creation of the fault data structure of chemical plants using the methods described in papers (69) - (75). The plant configuration and models are entered on a computer crt, a fault propagation structure is created in the computer, and this is then interrogated as required to provide, e.g. a fault tree on a graph plotter, a set of minimum cut sets, or a data structure for an alarm analysis computer.

The basic principles are established and renewed emphasis is being placed on the quality of the models used. Paper (76) is a review of some of the basic event /fault information which must be taken into account in such models.

Papers (77) - (79) are concerned with plant engineering. Paper (77) describes developments in the Department of Chemical Engineering at Loughborough University of Technology, paper (78) developments in plant engineering in general and paper (79) the M.Sc. Course in Plant Engineering in the Process Industries at Loughborough.

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In publications written with M.Sc. and Ph.D. students and with temporary research staff my contribution was that which normally pertains in such circumstances.

In all other publications I regard the contributions as shared equally between the authors subject to the comments given below.

Publ. 1 I was the junior author in this paper

Publ.12 This paper arose from Bosley's Ph.D. work. I recognized that his numerical results indicated a connection between the continued fraction expansion and moments methods. The main part of the mathematical derivation was due to H.W. Kropholler

Publ.18 I was the senior author in this paper

Publ.26 This book arose from an Institution of Chemical Engineers' Industrial Research Fellowship on "Man-Computer Interaction in Process Control", shared with E. Edwards. Broadly Edwards contributed the human factors material and I the rest, but we both reviewed the whole text together

Publ.27 I was principally responsible for editing this collection and contributed a review paper to it (Publ.28)

Publ.37 I was the senior author in this paper

STATEMENT OF WORK PREVIOUSLY SUBMITTED

I was awarded a Ph.D. of Loughborough University of Technology in 1969. The title of the thesis was 'Unsteady-State Models of Gas Absorption Columns'. This work covers the material described in publications (2),(3),(7),(8),(9) and (4). The first four of these publications were published before the thesis and are referred to therein (p.7).

SIMILARITIES BETWEEN PAPERS

Papers 21 and 22 are identical. Papers 66 and 67 are very similar. Papers 48 - 52 treat the same theme but from different angles.

REFEREED AND UNREFEREED WORK

The material submitted includes both refereed and unrefereed work, but it is appreciated that the assessment is based mainly on the former.

Ph.D. THESES SUPERVISED

1971 S. N. Anyakora, "Malfunction of process instruments and its detection using a process control computer"

1972 M. J. Bosley, "Simplification of linear unsteady-state models of chemical processes"

1973 P. K. Andow, " A method for process computer alarm analysis"

1973 P. Sheppard, "The determination of plate efficiencies in unsteady-state plate column models"

1976 B. Bellingham, "The detection of malfunction using a process computer"

1978 G. A. Martin-Solis, "Fault tree synthesis for real time and design applications in process plant" (supervised jointly with P. K. Andow, principal supervisor)

1979 D. J. Sherwin, "Reliability applied to maintenance (supervision of research contract rather than of author himself or of his Ph.D. thesis as such)

SERC RESEARCH CONTRACTS HELD

1972-75 The detection of malfunction using a process computer

1974-77 Alarm analysis using a process computer

1975-78 The use of reliability engineering in decision-making on the maintenance of process plant

1978-81 The propagation of faults in chemical process plants

1981-84 The modelling of fault conditions in chemical process plants

1982-85 The hazard control of major hazard installations (SERC/SSRC)