Final Report for Project Process Control 1.7 1969 -- 30.6 1970

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1970

Document Version:
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TFRT-4002

FINAL REPORT FOR PROJECT PROCESS CONTROL 1.7 1969 - 30.6 1970 CONTRACT 69-631/U489 SWEDISH BOARD FOR TECHNICAL DEVELOPMENT

K.J. ÅSTRÖM

REPORT 7008 OCTOBER 1970
LUND INSTITUTE OF TECHNOLOGY
DIVISION OF AUTOMATIC CONTROL

FINAL REPORT FOR PROJECT PROCESS CONTROL 1.7.1969 - 30.6.1970
CONTRACT 69-631/U489 SWEDISH BOARD FOR TECHNICAL DEVELOPMENT

K.J. Åström

ABSTRACT

This report covers the third year of the process control project at the Division of Automatic Control at Lund Institute of Technology. The project contains four parts: System Identification, Adaptive Control, Numerical Methods for Optimal Control and Applications.

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1. INTRODUCTION

The project is part of a long range program in the area of process control. A program covering the first three years period is given in reference [1]. The results obtained during the first and second years are reported in [2], [6]. This report covers the results obtained during the third year. A detailed program for this activity is given in [5]. We have essentially been able to follow the original plans. Based on the results obtained a new three year program was also formulated in 1969. See [4]

All research at the Institute has been centered around the process control project. Contributions have been given by four research engineers supported by the Swedish Board of Technical Development (STU) as well as students and staff of the Institute. The work has been organized so that the research engineers have acted as project leaders in the areas : Process Identification, Numerical Methods of Optimal Control, Adaptive Control and Real-time Computation. A major effort has also this year been devoted to the evaluation, purchasing and installation of a Process Control Computer. A reasonable amount of time has also been devoted to training the staff to handle the computer. The major coordinating function has been done by K.J. Åström, this year through remote control from USA.

2. PROCESS IDENTIFICATION

2.1 Introduction

Process identification has been one of the major activities of our group. The work has been divided into the areas of off-line identification, multivariable systems and real-time identification. The identification of linear single output or single input systems is now well understood. We have several efficient numerical algorithms available as well as computational experiences on industrial data. The major problems which remain are identification of larger systems, structural problems for multivariable systems, choice of sampling intervals and input signals.

The real-time identification problem is still in its infancy. We have several algorithms which are operating very well but analysis and convergence proofs are still lacking.

In the last IFAC symposium on Identification and Process Parameter Estimation our group contributed the following papers.

Åström K.J. and Eykhoff P. "System Identification - a survey".

Valis J. "On-line Identification of Multi-variable Linear Systems of Unknown Structure from Input Output Data".

Wieslander J. and Wittenmark B. "An Approach to Adaptive Control using Real-time Identification".

Gustavsson I. "Comparison of Different Methods for Identification of Linear Models for Industrial Processes".

2.2 Off-line Identification

Off-line identification of linear systems with one input or one output have been studied extensively. Several techniques have been tried. One of the most powerful being the maximum likelihood technique which has been developed at the

Institute. Different identification techniques have been applied to a large number of industrial measurements, including dynamic experiments as well as time-series analysis. A survey of some results obtained is given in Gustavssons Prague-paper which was mentioned above.

Through extensive contacts with industry we have obtained extensive sets of industrial data. Among the contributors we mention: AB Isotop Teknik, AB Sydkraft, OECD Halden Reactor Project, and SAAB. Collaboration with Billman Regulator AB and AB Alfa-Laval has also been initiated. Contacts have been established with various research groups at the Lund University Hospital. The industrial processes that have been modeled are a boiler, a paper machine, nuclear reactors, super heaters and thermal radiators.

Results are given in the following reports:

Jonson A. and Ström L-M "Process-identifiering av husdynamik - radiatorer och värmeväxlare". (Identification of thermal dynamics of buildings - radiators and heat exchangers), Report 6922, November 1969.

Elfving T. and Hultberg T. "Mätning och identifiering av dynamiken på torkpartiet i en pappersmaskin". (Measurements and Identification of the Dynamics of the Drying Section of a Paper Machine), Thesis Report RE-57, July 1969.

Klöver L. and Olsson L-E. "Identifiering av Haldenreaktorns dynamik med maximum-likelihood metodik". (Identification of dynamics of the Halden reactor by the maximum likelihood method), Thesis Report RE-65, October 1969.

The advantage of working with real data can not be underestimated. It has now been demonstrated in a large number of cases that there exist many techniques proposed in literature which work very well on simulated data but not so well on real data. Examples are to be found in:

Johansson C. and Malmquist L-G. "Processidentifiering med hjälp av impulssvar och stegsvar". (Process identification by impulse response and step response technique), Thesis Report RE-64, November 1969.

Jonson A. and Ström L-M. "Processidentifiering - en jämförelse av störningskänsligheten hos spektralanalys och maximum likelihood metoden". (Process identification - a comparison of the sensitivity of spectral analysis and the maximum likelihood method), Report 6917, August 1969.

The main conclusion which can be drawn from the specific examples is that the maximum likelihood method is superior to the other techniques where the signal to noise ratio is low. It has also been demonstrated that serious mistakes can be committed in parametric identification if the model has the wrong structure.

Experiences from solution of practical identification problems have shown that it is not always easy to find the order of the model and to estimate time-delays. It is also a problem to handle processes with time-constants that are long compared to the sampling interval. The choice of input signal and sampling interval have also been studied. It has been shown by examples that the choices may have a drastic influence on the accuracy of the identification. These problems have been analysed theoretically for simple cases and by simulations in more complex situations. Some preliminary results have been obtained. It has been shown that the rules for choice of parameters of a PRBS signal for correlation analysis published in the litera-

ture are not suitable for identification if the data will be analysed by parametric methods. Rules of thumb for the choice of sampling interval have been given.

2.3 Multi-variable and non-linear systems

The essential difficulty with the identification of non-linear and multi-variable system is the choice of structures. An attempt to find minimum parameter structure for multi-variable systems have been made in:

Valis J. "On-line identification of multi-variable linear systems of unknown structure from input - output data". IFAC Prague 1970.

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One key problem is the question of identifiability i.e whether or not a certain combination of parameters can be determined from input output data. Preliminary results in this direction have been obtained in:

Bellman R. and Åström K.J. "On structural Identifiability" Mathematical Biosciences 7 (1970) 329-339.

The problem will however require further study.

The computational aspects on identification of multi-variable systems is important. In the report:

Åström K.J. "Computational aspects of a class of identification problems". Department of Electrical Engineering, University of Southern California, Report 69-14, October 1969.

various ways to make trade-offs between computing time and storage are discussed. A particular technique which saves computing time by using a lot of memory has been programmed by K.Eklund. This algorithm has been investigated in:

Edwardsson A. and Ekwall U. "Identifiering av parametrar i tillståndsmodeller, en icke-rekursiv metod som bygger på variationskalkyl". (Identification of parameters of state space models, a non-recursive method using calculus of variations), Thesis Report RE-79, April 1970.

Algorithms which represent the other extreme can be obtained by various ad hoc extensions of the Kalman filtering theorem. This has been explored in:

Brännström J. and Johansson A. "Identifiering av parametrar i tillståndsmodeller med rekursiv teknik, s.k. extended Kalman-filter. (Identification of parameters of state space models by recursive technique, extended Kalman-filtering). Thesis Report RE-78, April 1970
and
Holst J. "Identifiering av parametrar i tillståndsmodeller med hjälp av tidsdiskreta iterativa filter" (Identification of parameters of state space models by time discrete iterative filtering), Thesis Report RE-81, June 1970.

Nuclear reactors and thermal power-stations are excellent examples of multi-variable systems. In collaboration with the OECD reactor group in Halden and AB Sydkraft we have made measurements on such systems. These experiments give realistic examples to test multi-variable system identification techniques.

2.4 Real-time Identification

This field is still in its infancy. It has been shown in:

Wieslander J. "Real-time identification - Part 1", Report 6908, November 1969.

that efficient algorithms can be obtained through extensions of Kalman filtering. (Compare fig 2.1). Exploratory studies of such algorithms have been done. It has been shown that they can behave extraordinary well. There are, however, many deep theoretical questions which must be analysed further. The most important problem is the question of stability of the algorithms, which is a very hard analysis problem.

The problem of handling bias in the measurements have been investigated. The normal way to do this in off-line computation is to subtract the average from both the input and the output. This can not be done in real time. A promising solution to this problem has been found and is described in the report mentioned above.

When using non-linear filtering techniques it is also necessary to make a priori assumptions of the drift rates of the parameters. This is frequently done by guesswork. This approach has, however, now been abandoned in favour of using the full maximum likelihood technique. A subroutine that maximixes the likelihood function has been written thus eliminating a great deal of the arbitrariness in the earlier techniques. Techniques to test the system orders have also been developed.

3. ADAPTIVE CONTROL

The work on adaptive control has been persued along two lines e.g.

- Exploitation of stochastic control theory.
- Analysis of particular adaptive algorithms.

Using stochastic control theory the adaptive control problem can be formulated as a stochastic control problem. The solution in this case leads to a functional equation, which can be solved using dynamic programming. For computational reasons the functional equation can only be solved for systems of low order. A simple case is treated in:

Wittenmark B. "On adaptive control of low order systems", Report 6918, August 1969.

where a static system with a time varying gain is analysed. The optimal control algorithm is computed. It is shown that the regulator executes dual control in Feldbaums sense. The behaviour of the optimal regulator is also compared with various suboptimal regulators. The phenomenon of turn off which was previously discovered have also been investigated.

Since a straight-forward approach using stochastic control leads to prohibitive computations it is interesting to ask if there are special cases which lead to analytical solution. This problem is discussed in:

Åström K.J. and Wittenmark B. "Problems of Identification and Control". J. Math. Anal. and Applications, Dept. of Electrical Engineering, University of Southern California, Report 69-20, November 1969.

where the relationships between identification and control are discussed. The cases which lead to analytic solutions do not exhibit the dual control feature. In spite of the non dual behaviour this type of algorithm may have an application as self-adjusting regulators in process control systems.

Suboptimal dual regulators have been investigated in:

Wieslander J. and Wittenmark B. "An approach to adaptive control using real-time identification", presented at the Second Prague IFAC Symposium on Identification and Process Parameter Estimation, 15-20 June 1970.

and

Brantmark H. "Reglering av tidsvariabla system med Kalmanteori", (Control of time variable systems by means of Kalman theory),Thesis Report RE-76, March 1970.

The systematic comparison of different adaptive algorithms proposed in the literature has been continued. A scheme proposed by Roger Bakke has been studied in:

Nilsson A. and Svegne T. "Undersökning av Bakkes adaptiva regulator". (Examination of the Bakke adaptive controller), Thesis Report RE-68, January 1970.

and Tsypkin's learning model approach has been persued in:

Pauli A. "Adaptiv regulator baserad på lärande modell",(An adaptive controller based on a learning model), Thesis Report RE-74, February 1970.

4. NUMERICAL METHODS FOR OPTIMAL CONTROL.

This program has the purpose of developing algorithms in order to make optimal control theory a practical design tool. The research involves analysis of particular problems and published algorithms as well as theoretical studies of new algorithms.

4.1 Program library

During this period a new computer (UNIVAC 1108) was installed at the University Computing Centre. A significant effort has been devoted to change the programs which were previously running on other computers. The program library is continuously being extended. It contains 63 algorithms now. A major revision would, however, be necessary in order to make the algorithms generally available.

The problems of computing Lyapunov-functions for linear systems and quadratic lossfunctions for linear systems have been given special attention in the report:

Hagander P. "Numerical solution of $A^TS + SA + Q = 0$", Report 6920, October 1969.

An exploratory study of simulation algorithms has also been done in:

Larsson L.O. "Algoritmer för lösning av system av ordinära differentialekvationer". (Comparison of some numerical methods to solve ordinary differential equations), Thesis Report RE-77, April 1970.

4.2 Optimal control of non-linear systems

The Riccati equation plays a central role in linear regulation and prediction problems. New results have been established in:

Mårtensson K. "On the matrix Riccati equation", Report 7002, April 1970.

where the problem of existence of multiple steady state solutions to the Riccati equation is investigated. The results give a deeper insight into the linear regulator problem. They also give examples where the numerical solution of the Riccati equation can be extremely difficult.

Suboptimal regulators where the feedback is taken from a few statevariables only are discussed in:

Mårtensson K. "Suboptimal linear regulators for linear systems with known initial-state statistics", Report 7004, July 1970.

A decomposition technique which makes significant reductions in dimensionality possible have been proposed by Dr. Collins of USC. Dr. Collins visited Lund and lectured about his technique. An application was later studied in:

Glad T. "Diagonal dekomponering. Analys och tillämpningar på linjärkvadratiska problem". (Analysis and application of diagonal decompostion on linear-quadratic problems), Thesis Report RE-80, June 1970.

In this report a counter-example, which shows that the decomposition technique generally gives algorithms which converge to the wrong result, is also given.

The application of the linear regulator theory to the design of time-varying gains in an automatic landing system are discussed in:

Johnfors U. "Dimensionering av automatiskt landningssystem för flygplan. En tillämpning av linjärkvadratisk teori", (Synthesis of an automatic landing system for aeroplanes), Thesis Report RE-75, February 1970.

Applications to ships steering control are given in:

Ekdahl K.I. and Henriksson O. "Om regulatorer för maximal ekonomisk styrning av fartyg".(Regulators for optimal long-distance steering of large vessels), Thesis Report RE-83, July 1970.

4.3 Non-linear problems

A major effort has been devoted to develop a fairly general program based on Differential Dynamic Programming. Using this program it is now possible to solve optimal control problems with constraints on the control variable. The algorithm requires a fast computer with a large core storage. It is not possible to use the result on comparatively small process computers. The program has been applied to a specific problem discussed in :

Hagander P. "Minimal time problem for an inverted pendulum", Report 6921, October 1969.

which was previously solved with other techniques. Work is currently in progress on an application to optimal container handling.

An application of dynamic programming to the control of a rolling mill is given in:

Källström C. "Optimering av valsinställningarna i ett valsverk", (On optimal roll settings of a rolling mill), Thesis Report RE-73, January 1970.

where the problem is to minimize the number of passes through the mill. (See fig. 4.1)

4.4 Production planning

It appears that production planning problems might be very good applications for optimal control theory. In collaboration with Billerud AB we are studing a production control problem. In the report:

Pettersson B. "Mathematical methods of a pulp and paper mill scheduling problem", Report 7001, April 1970.

it is shown that a production planning problem can conveniently be formulated as an optimal control problem. This approach is shown to give computational algorithms which are significantly shorter than those obtained by other techniques. The algorithms obtained have been sucessfully implemented into routine planning procedures.

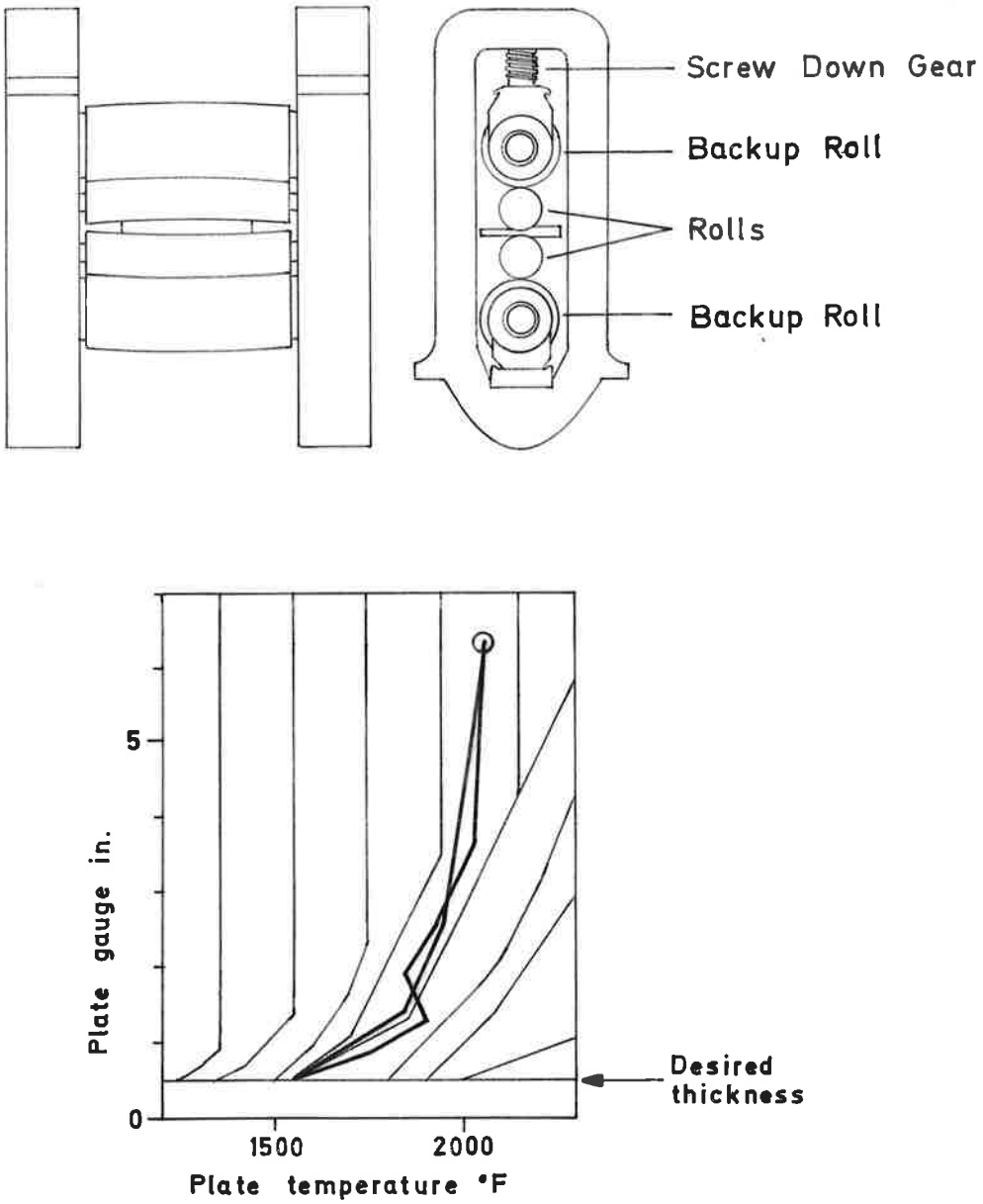

Fig. 4.1
Schematic diagram of a four high hot plate mill. The state variables are plate temperature and gauge. There are constraints on the roll force and on rolling temperature. The cost a linear combination of required time and energy is minimized by Dynamic Programming. The computer optimal trajectories are shown in the figure. The heavy lines represent actual data from two slabs rolled at Oxelösunds Järnverk AB.

5 APPLICATIONS

5.1 Introduction

The effort in applications have been somewhat greater than anticipated in the original research programs. We have thus found i easier than we anticipated to obtain real industrial data for the identification. The success of our techniques has also made it possible to exchange data with other international research groups. Due to lack of funds we have not been persuing the project thermal boilers full-time. The major effort in the area of applications during the year have thus been in the following fields: Thermal boilers, nuclear reactors, development of the process control laboratory with a process computer and associated equipment.

5.2 Thermal boilers

In cooperation with Sydsvenska Kraft AB identification experiments were made on a 160 MW power station in June 1969. Five different experiments using fuel flow, feedwater flow, two coolant flows and control valve position as input signals were made at two load levels. Preliminary identification using the maximum likelihood techniques has given good results. Time constants ranging from 20 - 700 sec. have been found. Transports delays are of the order of magnitude of 10 - 20 seconds. The order of the subsystems have never exceeded 3. The experiments have given good insight into the crosscoupling between different physical variables of the process. The preliminary models obtained have been compared with models which were developed earlier, in reports 6809 and RE-55. Simulations using the same input signals as in the field experiments have made it possible to compare the model outputs with recorded data. A comparison indicates that the approximations made in the earlier reports are relevent and that it is possible to derive reliable low order models from construction data. (Compare fig. 5.1) The results in this respect

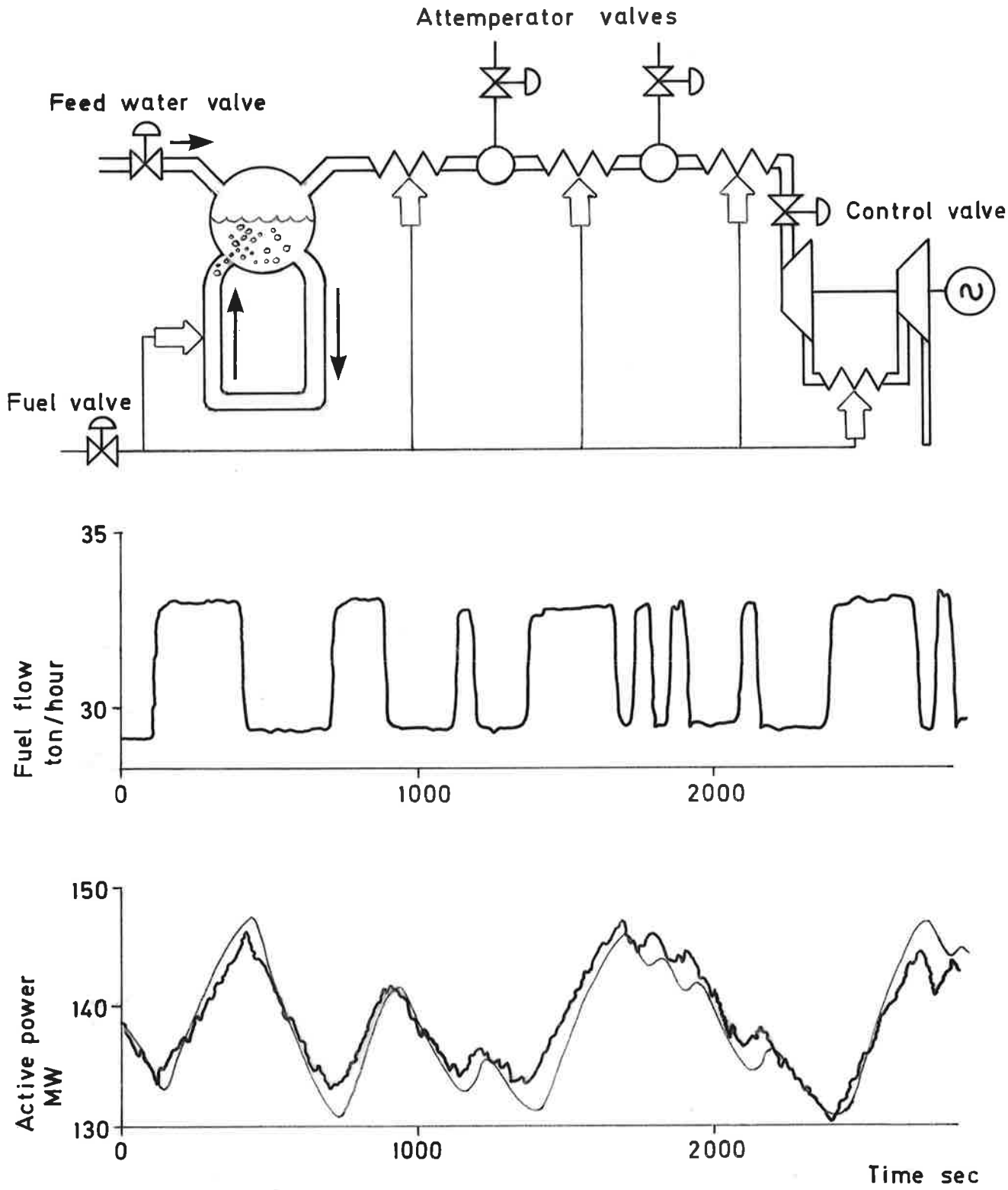

Fig. 5.1
Schematic diagram of thermal power plant and data from an identification experiment designed to determine the dynamics relating active power to fuel flow. The heavy line is actual measured power and the thin line is the power computed from a model determined from construction data.

are very encouraging.

5.3 Nuclear reactor dynamics

Several experiments have been performed at the OECD Halden Reactor in order to determine its dynamics. The experimental data has been analysed by the programs developed by I. Gustavsson. The plant is normally controlled by three inputs, the control rods and two steam valves. Tor safety reasons only single loop experiments have so far been made but multivariable experiments are planned. The control rod-nuclear power loop has been analysed in detail. Some difficulties have arisen during the computations. The main reasons are the extreme spread of eigenvalues and a bad choice of sampling interval in the experiments. Experiments with better sampling intervals are planned in the future. Different process models have been compared. The results of the identifications have been checked with simulations of a theoretical state model and with other identification techniques. Some of the results are reported in:

Klöver L. and Olsson L-E. "Identifiering av Haldenreaktorns Dynamik med Maximum-Likelihood Teknik", (Maximum-likelihood identification of the Halden reactor), Thesis Report RE-65, October 1969.

5.4 Real-time computing

One of the major obstacles towards an economic installation of computer in a process industry is lack of understanding of real-time computing processes. An initial effort to look into this problem has been initiated. There has been a small delay in the project because Digital Equipment Corporation was not able to deliver the process computer in time. The computer was delayed five months. One man has been on a two week programming course in the USA. Upon his return he has organized similar courses to share his knowledge with other members of our group. A manual, whose purpose is to introduce the computer

to the students and personel has been written.

Wieslander J. "Introduction to PDP-15".

Programs to control the process I/O facilities have been written. An interface including A/D and D/A converters and multiplexers has been built at the Institute.

5.5 Thermal process

A one dimension thermal diffusion process with two inputs and seven outputs has been prepared. The process is designed to operate in a temperature interval 20°C to 30°C. A schematic diagram is given in fig 5.2.

The process consists of a shielded homogeneous copper rod with constant cross section. The shield is controlled in the same way as the rod and reduces the radial heat flow. The ends of the rod are temperature controlled by Peltier effect elements. This makes it possible to increase and decrease the temperature in both ends. The rod is equiped with six equidistant temperature sensors (thermistors). The maximum linearity error of the sensors is .01°C in the temperature range 20°C - 30°C. The 12 hour stability is better than .001°C. Compensation for the non-linear current power characteristics of a Peltier effect element is provided. The solution time of the servos is five seconds with a 2°C temperature change of the reference point. The influence of the environment on the stationary temperature distribution is .02°C in the interval 20°C - 30°C. Reports describing the sensors and the equipment are in preparation.

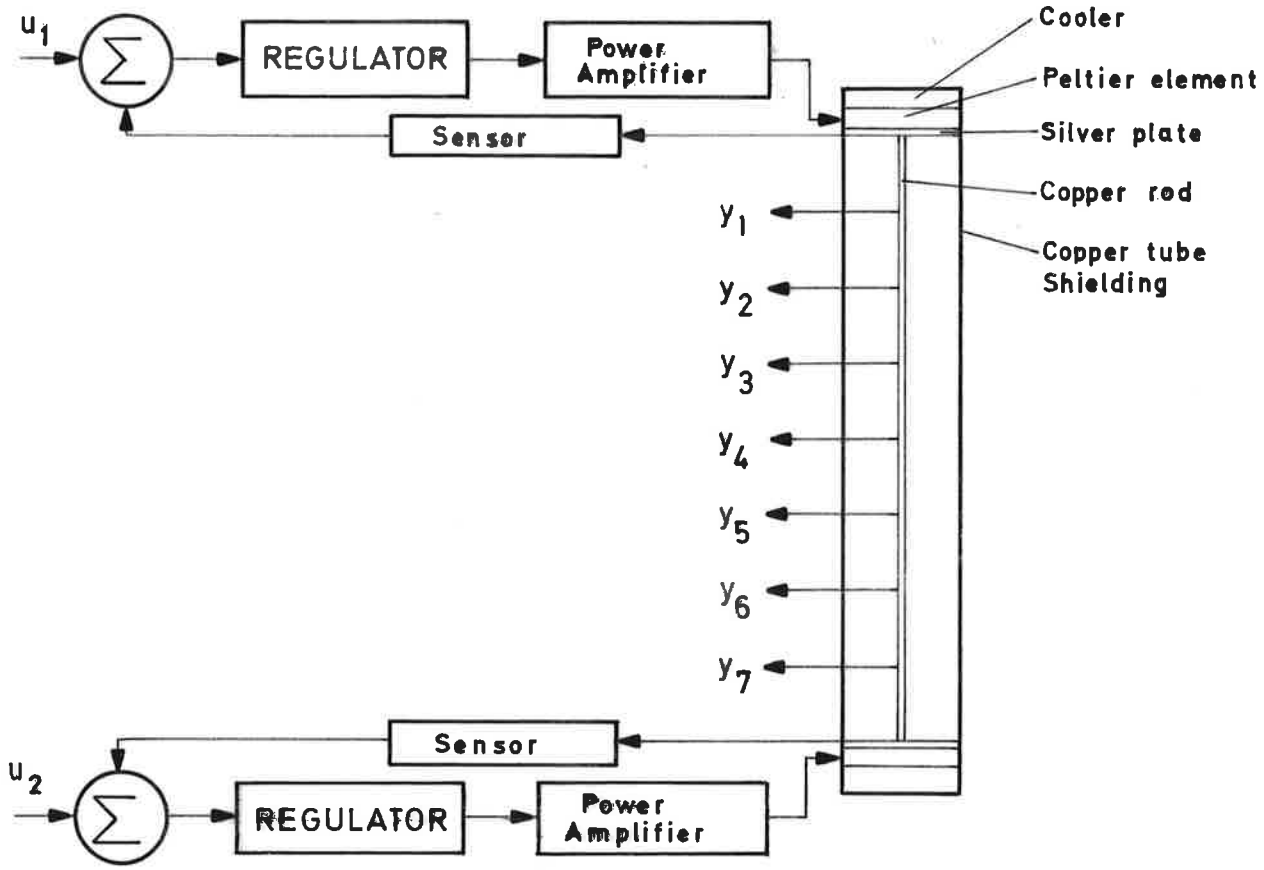

Fig. 5.2

Schematic diagram of multivariable thermal process.

6. CONTACTS WITH INDUSTRY

The industrial development in the area of process control is steadily increasing, mainly due to the decreasing price and increasing performance of small process computers. A close contact with industry is judged to be very valuable for both parts. The major motivations are

- to provide industry with knowledge of theoretical tools currently available.
- to give a realistic foundation for theoretical work.
- to find new problems.

It is our policy to act vigorously in order to contribute towards bridging the gap between theory and practice. Several forms of contacts have been tried.

- courses
- contact meetings ("kontaktdagar")
- joint projects

6.1 Courses

In collaboration with "Svenska Teknologföreningen" a course "Reglerteorier i omdaning", (New Ideas and Concepts of Control Theory) was arranged. The course is directed towards the praticing engineer. The course is planned to be held in next year too.

6.2 Contact meetings

In order to establish new contacts with industry we have tried a system with contact meetings in Lund. Up to now we have had five meetings which have been successful. Several concrete results have come out of the meetings.

In May 12 - 13, a meeting with the topic "Programming Systems for Process Computers" was arranged. Twenty persons outside the groupe participated. Among the participants we mention:FOA, Billerud, Statskontoret, Haldor Topsøe, ASEA, SINTEF, Servo-laboratoriet, Sydsvenska Kraft AB, AB Atomenergi, AB Iggesunds Bruk, LM Ericsson, Regnecentralen, Kockums Mekaniska Verkstad. A summary of the program and the discussions is given by G. Olsson in:

"Programsystem för processdatorer, Kontaktdagar med industrin vid Institutionen för Reglerteknik, 12 - 13 maj 1970", (Program Systems for Process Computers, Contact Meeting with industry at the Division of Automatic Control, 12 - 13 May 1970).

6.3 Joint projects

Most joint projects have been in connection with the education program. Production Control of a paper mill has been investigated jointly with Billerud AB. This study has given good results and has resulted in the implementation of a production control system which is operating successfully, the problem seems to be a fairly general one and I suspect that similar applications can be made in other industries.

Extensive measurements on a 160 MW boiler have been done in collaboration with Sydkraft AB. We are modeling and identifying a nuclear reactor jointly with the OECD project in Halden.

Identification of heat exchangers has been done with Alfa-Laval AB in Lund. Experiments on heating systems for buildings are done in collaboration with Billman.

A non-technical problem modelling of an ecological system - the lake Trummen - is done in collaboration with the Institutes of Limnologi and Ekologisk botanik at the University of Lund.

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[3] Åström K.J. "Ansökan till STU beträffande processregleringsprojektet för år 68/69", Lund den 25.3.1968.

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[6] Åström K.J. and Olsson G. "Final Report for project Process Control 1.7.1968 - 30.6.1969 Contract 68-336-f Swedish Board for Technical Development, Report 6919, October 1969, Lund Institute of Technology.

[7] Åström K.J. "Ansökan till STU beträffande processregleringsprojektet för år 70/71", Lund.

APPENDIX A - LIST OF PERSONEL

Professor	Karl Johan Åström
t.f. prof.	Karl Eklund
t.f. univ.lekt.	Gustaf Olsson
Forskningsing.	Ivar Gustavsson
"	Krister Mårtensson
"	Johan Wieslander
"	Björn Wittenmark
Assistenter	Per Hagander
"	Sture Lindahl
"	Gunnar Bengtsson
"	Ulf Borisson
Övn. ass.	Alf Bengtsson
"	Thomas Brunkstedt
"	Hans Engwall
"	Anders Jonson
"	Jan Klevås
"	Leif Klöver
"	C-G Källström
"	Carl Johan Lamm
"	Ulf Larsson
"	Christer Ljung
"	Ingemar Nordh
"	L-E Olsson
"	Lennart Stenberg
"	L-M Ström
"	Per Torlöf
Forskn.ing.	Olle Fjelner
Lab.ing.	Jaroslav Valis
Instr.makare	Rolf Braun
Doktorander	Bo Leden
"	Torsten Söderström
Tekn.biträde	Birgitta Tell/Bengt Lander
Sekreterare	Lena Jönsson

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Åström K.J. "Introduction to Stochastic Control Theory", Academic Press N.Y. 1970.

Åström K.J. "On the choice of sampling rates in parametric identification to time series", Information Sciences 1 1969, (273-278).

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Åström K.J. and Eykhoff P. "System identification - a survey", 2nd IFAC Symposium on Identification and Process Parameter Estimation, Prague June 1970.

Eklund K. "Numerical modelbuilding", International Journal of Control, 1970, Vol.11, No.6.

Gustavsson I. "Comparison of different methods for identification of linear models for industrial processes", 2nd IFAC Symposium on Identification and Process Parameter Estimation, Prague June 1970.

Valis J. "On-line identification of multivariable linear systems of unknown structure from input output data", 2nd IFAC Symposium on Identification and Process Parameter Estimation, Prague June 1970.

Wieslander J. and Wittenmark B. "An approach to adaptive control using real-time identification", 2nd IFAC Symposium on Identification and Process Parameter Estimation, Prague June 1970.

APPENDIX C - TECHNICAL REPORTS

(1) Report 6908 Wieslander, Johan: Real-time identification - Part 1, Nov-69.

(2) Report 6910 Olsson, Gustaf: Spatial xenon instability i in thermal reactors, July-69.

(3) Report 6911 Olsson, Gustaf: Digital simulation of spatial xenon oscillations, July-69.

(4) Report 6917 Jonson Anders and Ström, Lars-Magnus: Process-identifiering - en jämförelse av störningskänsligheten hos spektralanalys och maximum-likelihood metoden. (A comparison of the sensitivity in the correlation and maximum-likelihood methods in process identification), August-69.

(5) Report 6918 Wittenmark Björn: On adaptive control of low order systems, August-69.

(6) Report 6919 Åström Karl Johan and Olsson Gustaf: Final Report for Project Process Control 1.7. 68 - 30.6.69 Contract 68-336-f Swedish Board for Technical Development, October-69.

(7) Report 6920 Hagander Per: Numerical solution of $A^TS + SA + Q = 0$, October-69.

(8) Report 6921 Hagander Per: Minimal time problem for an inverted pendulum. Maximum principle and phase plane discussion, October-69.

(9) Report 6922 Jonson, Anders and Ström, Lars-Magnus: Process-identifiering av husdynamik - radiator och värmeväxlare. (Identification of the temperature dynamics in a building), November-69.

(10) Report 7001 Pettersson, Bengt: Mathematical Methods of a Pulp and Paper Mill scheduling Problem, April-70.

(11) Report 7002 Mårtensson, Krister: On the matrix Riccati equation. Thesis for the degree of Teknologie Licentiat, April-70.

APPENDIX D - THESIS IN AUTOMATIC CONTROL FOR THE DEGREE OF CIV.ING., LUND INSTITUTE OF TECHNOLOGY

RE-57 Elfving, Thomas och Hultberg, Thomas: Mätning och identifiering av dynamiken på torkpartiet i en pappersmaskin. (Measurements and Identification of the Dynamics of the Drying Section of a Paper Machine), Juli-69.

RE-58 Bengtsson, Gunnar: Förfiltrering av signaler med Kalmanfilter. (Optimal Prefiltering with Kalman Theory), Juli-69.

RE-59 Rosengren, Bengt och Nordh, Ingemar: Konstruktion av PRBS-generator. (Construction of a PRBS Generator), Juli-69.

RE-60 Ekengren, Birger: Bestämning av radiatordynamiken i ett hyreshus. (Determination of the radiator temperature dynamics in a building), Juli-69.

RE-61 Folkesson, Per-Åke och Hjersing, Torsten: Mätning av temperatur och tryck med pulsfrekvensteknik. (Temperature and Pressure Measurements with Pulse Frequency Techniques), Juli-69.

RE-62 Sjöberg, Mats: Uppbyggnad av servo för inverterad pendel. (Construction of a servo to control an inverted pendulum), Aug-69.

RE-63 Källrot, Björn: Undersökning av direktmatningen i ett adaptivt modellreferenssystem. (Examination of a direct signal path in an adaptive model reference system), Sept-69.

RE-64 Johansson, Christer och Malmqvist, Lars-Gunnar: Processidentifiering med hjälp av impulssvar och stegsvar. (Process identification from impulse and step responses), Nov-69.

RE-65 Klöver, Leif och Olsson, Lars-Erik: Identifiering av Haldenreaktorns dynamik med maximum-likelihood metodik. (Maximum-likelihood identification of the Halden Reactor), Okt-69.

RE-65 Trovik, Hans: Projektering av elektromekanisk presentationsarm. (Outline of a electromechanical demonstration arm), Okt-69.

RE-67 Fick, Göran: Flervariabla system. (Multivariable systems) Okt-69.

RE-68 Nilsson, Allan och Svegne, Tor: Undersökning av Bakkes adaptiva regulator. (Examination of the Bakke adaptive controller), Jan-70.

RE-69 Fors, Roland och Mårtensson, Jan: Integrator för sampling av processignal. (Construction of an integrator for sampling), Jan-70.

RE-70 Brunkstedt, Thomas och Silvén, Ulf: Processdator. En studie av några svenska installationer. (Some industrial process computer installations in Sweden), Jan-70.

RE-71 Gustafsson, Bengt: Tankreaktorn. Analys och syntes av några olika kemiska reaktionssystem. (Analysis and synthesis of some different chemical stirred tank reactors), Jan-70

RE-72 Lundström, Lennart (tillsammans med Ulla Larsson CTH): Temperatursensor med känselkropp av bimetall för styrning av en effektfluidistor. (A temperature sensor with sensing element of bimetal for control of a fluid amplifier for heavy current), Sept-69.

RE-73 Källström, Claes: Optimering av valsinställningarna i ett valsverk. (On optimal roll settings of a rolling mill), 1970.

RE-74 Pauli, Andreas: Adaptiv regulator baserad på lärande modell (An adaptive controller based on a learning model),Feb-70

RE-75 Johnfors, Ulf: Dimensionering av automatiskt landningssystem för flygplan. (Synthesis of an automatic landing system for aeroplanes), Feb-70.

RE-76 Brantmark, Håkan: Reglering av tidsvariabla system med Kalman-teori. (Control of time variable systems by means of Kalman theory), Mars-70.

RE-77 Larsson, Lars-Åke: Algoritmer för lösning av system av ordinära differentialekvationer. (Comparison of some numerical methods to solve ordinary differential equations), April-70

RE-78 Brännström, Jan och Johansson, Allan: Identifiering av parametrar i tillståndsmodeller med rekursiv teknik, s.k. extended Kalman filter. (Recursive Parameter estimation in multivariable systems with extended Kalman filtering), April-70.

RE-79 Edwardsson, Anders och Ekwall, Ulf: Identifiering av parametrar i tillståndsmodeller. En icke-rekursiv metod som bygger på variationskalkyl. (Non-recursive parameter estimation in multivariable systems), April-70.

RE-80 Glad, Torkel: Diagonal dekomponering. Analys och tillämpning på linjärkvadratiska problem. (Analys and application of diagonal decomposition on linear-quadratic problems) Juni-70.

RE-81 Holst, Jan: Identifiering av parametrar i tillståndsmodeller med hjälp av tidsdiskreta iterativa filter. (Recursive parameter estimation in multivariable systems with iteration filter), Juni-70.