AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

DESIGN OF A COMPUTERIZED ADAPTIVE PRESSURE CONTROL SYSTEM

By

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THESIS

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بسم الله الرحمن الرحيم

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of master in mechanical engineering.

The work included in this thesis was carried out by the author in the Department of Energy and Automotive Engineering, Ain Shams University, from 1985 to 1990.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

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INTRODUCTION AND RESUME

The present decade is considered to be a good witness on extensive theoretical work in the field of adaptive control. Specialists in the field have invited the research workers during a great number of conferences to concentrate their efforts in the practical applications of the previously introduced theories. This is the only way to verify the presented theories from the point of view of the engineering applications.

The survey presented in chapter [1] of this thesis represents a good document to prove the small number of works relevant to the experimental and practical applications. The published simulation results are considered to be a good proof for the efficiency of the theories of the adaptive control systems, while the real experimental and practical applications are the mother criterion for the feasibility of industrial implementation of such techniques.

The present work is considered to be a good approach for the practical application of some adaptive control concepts rather than, another new trial for new theoretical work. A great deal of effort has been devoted to the preparation and building of an experimental adaptive control station. The parametric adaptation strategy has been choosen in this work instead of a synthesis of adaptive control signals, which represents the true situation and the real implementation of the adaptation concepts in its true and realistic definition.

It is essential to emphasize the fact that the parametric adaptation approach is the core and the perspective base for effective control systems characterized by extremely wide variation in the process parameters such as in the field of autopilots, automatic guidance of aircrafts and missiles and a great number of process control systems and servomechanisms.

The adaptation mechanism adopted in this work is based on one of the best control criteria, which has been proved to be practical and accurate. The process considered in the adaptive control station does not represent a typical one for which the parametric adaptation is considered; but the concepts included in both the hardware and software can be considered the invariant part of a realistic adaptation mechanism.

Chapter [2] includes the basic ideas and concepts upon which the adaptive control station has been designed. Engineering of the identification methods, off-line calculations of the conventional controller tuning parameters based on either the ITAE criterion and the frequency response methods, and the adaptive control system configuration.

Chapter [3] introduces a brief description of the experimental adaptive control station, including the conventional pneumatic control contour beside the interfaces of that contour to the data acquisition- and control unite mastered by the control computer.

Chapter [4] includes the software flow chart and the implementation of the adaptation algorithm as a control program for the computer. The test procedures either for the conventional and the adaptive systems are included in this chapter. The whole set of results and a hard copy are given in the appendices and also in the text.

Chapter [5] includes the discussion of the results and the important conclusions of the presented work.

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3. CONSTRUCTION OF THE PROPOSED ADAPTIVE CONTROL SYSTEM

4. EXPERIMENTAL EVALUATION OF THE PROPOSED ADAPTIVE CONTROL ALGORITHM

5. DISCUSSION AND CONCLUSIONS

CHAPTER [1]

SURVEY ABOUT THE ADAPTIVE CONTROL

Progress in theory and systems applications of adaptive control is reviewed. Different approaches are discussed with particular emphasis on model reference adaptive systems and self tuning regulators, Techniques for analysing adaptive systems are discussed. This includes stability and convergence analysis. It is shown that adaptive control laws can also be obtained from stochastic control theory. Issues of importance for applications are covered. This includes parametric, tuning, and tracking as well as different ways of using adaptive control. An overview of applications is given.

1.1 INTRODUCTION

According to Webster,s dictionary, to adapt means "to change (oneself) so that one,s behavior will conform to new or changed circumstances". The word adaptive control have been used at least from the beginning of the 1950s. There is for example, a patent on an adaptive regulator by Caldwell (1950). Over the years there have been many attempts to define adaptive control (Truxal, 1964; Saridis, Mendel and Nikolic, 1973). Intuitively an adaptive regulator can change its behaviour in response to changes in the dynamics of the process and the disturbance. Since ordinary feedback was introduced for the same purpose, the question of the difference between feedback control and adaptive control immediately arises. A meaningful definition of adaptive control which makes it possible to look at a regulator and decide if it is adaptive or not is still missing. There appears, however, to be a consensus that a constant gain feedback is not an adaptive system. In this work I will therefore take the pragmatic approach that adaptive control is simply a special type of nonlinear feedback control. Adaptive control often has the characteristic that the states of the process can be separated into two categories, which change at different rates. The slowly changing states are viewed as parameters.

Research on adaptive control was very active in the early 1950s. It was motivated by design of autopilots for high performance aircrafts. Such aircrafts operate over a wide range of speeds and altitudes. It was found that ordinary constant gain, linear feedback can work well in one operating condition. However, difficulties can be encountered when operating point conditions change. A more sophisticated regulator which works well over a wide range of operating conditions is therefore needed. The work on adaptive flight control was characterized by a lot of enthusiasm, bad hardware and nonexisting theory. A presentation of the results is given in Gregory (1959) and Mishkin Braun (1961). Interest in the area diminished due to lack of insight and a disaster in a flight test (see Taylor and Adkins, 1965).

In the 1960s there were many contributions to control theory, which were important for the development of adaptive control. State space and stability theory were introduced. There were also important results in stochastic control theory. Dynamic programming introduced by Bellman (1957, 1961) and dual control theory introduced by Feldbaum (1960a, b, 1961a, b, 1965), increased the understanding of adaptive processes. Fundamental contributions were also made by Tsypkin (1971) who showed that many schemes for learning and adaptive control could be described in a common framework as recursive equations of the stochastic approximation type. There were also major developments in system identification and parameter estimation (Astrom and Eykhoff, 1971).

The interest in adaptive control was renewed in the 1970s. The progress in control theory during the previous decade contributed to an improved understanding of adaptive control. The rapid and revolutionary progress in microelectronics has made it possible to implement adaptive regulators simply and cheaply. There is now a vigorous development of the field both at universities and in industry.

There are several surveys on adaptive control. The early work was surveyed by Aseltine, Mancini and Sarture (1958); Stromer (1959) and Jacobs (1961).

Surveys of special areas in the field were given by Landau (1974); Wittenmark (1975); Unbehauen and Schmidt (1975); Parks, Schaufelberger and Schmidt (1980). The papers by Truxal (1964) and Tsypkin (1973) have also given enlightenment perspective. An extensive bibliography which covers more than 700 papers is given by Asher, Andresani and Dorato (1976). Three books, Narendra and Monopoli (1980); Unbehauen (1980); Harris and Billings (1981), contains representative collections of papers dealing with recent applications. When selecting the material of this survey part, I deliberately choosed to focus on the simplest types of adaptive regulators. The idea is to describe the principles behind those adaptive schemes which are now finding their way towards applications and products. This means that many interesting adaptive schemes are lift out. Self-optimizing controls were recently surveyed by Sternby (1980). Other forms of adaptations that occurs in learning systems and in biological systems are described in Saradis (1977); Mendel and Fu (1970).

1.2 APPROACHES TO ADAPTIVE CONTROL

Three schemes for parameter adaptive control-gain scheduling model reference control and self-tuning regulators-are described in a common framework. The starting point is an ordinary feedback control loop with a process and a regulator with adjustable parameters. The key problem is to fined a convenient way of changing the regulator parameters in response to change in process and disturbance dynamics. The schemes differ only in the way the parameters of the regulator are adjusted.

1.2.1 Gain scheduling

It is sometimes possible to find auxiliary variables which correlate well with the changes in process dynamics. It is then possible to reduce the effects of parameters variations by changing the parameters of the regulator as functions of the auxiliary variables figure (1.1). This approach is called gain scheduling because the scheme was originally used to accommodate changes in process gain only.

The concept of scheduling originated in connection with development of flight control systems. In this application the Mach- number and the dynamic pressure are measured by air data sensors and used as scheduling variables.
The key problem in the design of system with gain scheduling is to find suitable scheduling variables. This is normally done based on knowledge of the physics of a system. For process control the production rate can often be chosen as scheduling variable since time constants and time delays are often inversely proportional to production rate.

When scheduling variables have been obtained, the regulator parameters are determined at a number of operating conditions using some suitable design method. Stability and performance of the system are typically evaluated by simulation.
Particular attention is given to the transition between different operating conditions. The number of operating conditions is increased if necessary.

One drawback of gain scheduling is that it is an open loop compensation. There is no feedback which compensates for an incorrect schedule. Gain scheduling can thus be viewed as feedback control system where the feedback gains are adjusted by feed forward compensation. Another drawback of gain scheduling is that the design is time consuming. The regulator parameters must be determined for many operating conditions. The performance must be checked by extensive simulations. Gain scheduling has the advantage that the parameters can be changed very quickly in response to process changes. The limiting factors depend on how quickly the auxiliary measurements respond to process changes.

There is a controversy in nomenclature whether gain scheduling should be considered as an adaptive system or not because the parameters are changed in open loop. Irrespective of this discussion, gain scheduling is a very useful technique to reduce the effects of parameter-variations. It is in fact the predominant method to handle the parameter variations in flight control systems (Stein, 1980). There is a commercial regulator for process control Micro-Scan 1300 made by Taylor Instruments which is based on gain scheduling (Andreiev, 1977)

1.2.2 Model reference adaptive systems (MRAS)

Another way to adjust the parameters of the regulator is shown in figure (1.2). This schemes was originally developed by Whitaker, Yamron and Kezer (1958) for servo problem. The specifications are given in terms of a reference model which tells how the process output ideally should respond to the command signal. Notice that the reference model is part of the control system. The regulator can be thought of as consisting of two loops. The inner loop is an ordinary control loop composed of the process and the regulator. The parameters of the regulator are adjusted by the outer loop, in such a away that the error e between the model output ym and the process output y becomes small. The outer loop is thus also a regulator loop. The key problem is to determine the adjustment mechanism so that a stable system which brings the error to zero is obtained. This problem is nontrivial. It is easy to show that it cannot be solved with a simple linear feedback from the error to the controller parameters.

The MRAS was originally proposed by Whitaker and co- workers (1958). Further work was done by Parks (1966), Hang and Parks (1973), Monopoli (1973), Landau (1974) and Ionescu and Monopoli (1977). There has been a steady interest in the method (Hang and Parks, 1973). Landau,s book (Landau, 1979) gives a comprehensive treatment of work up to 1978. It also includes many references. Recent contributions are discussed in section (1.3).

The MRAS shown in figure (2) is called a direct scheme because the regulator parameters are updated directly. There are also other MRAS schemes where the regulator parameters are updated indirectly (Narendra and Valavani, 1979).

1.2.3 Self- tuning regulators (STR)

A third method for adjusting the parameters is to use the self-tuning regulator. such a system is shown in figure (1.3).

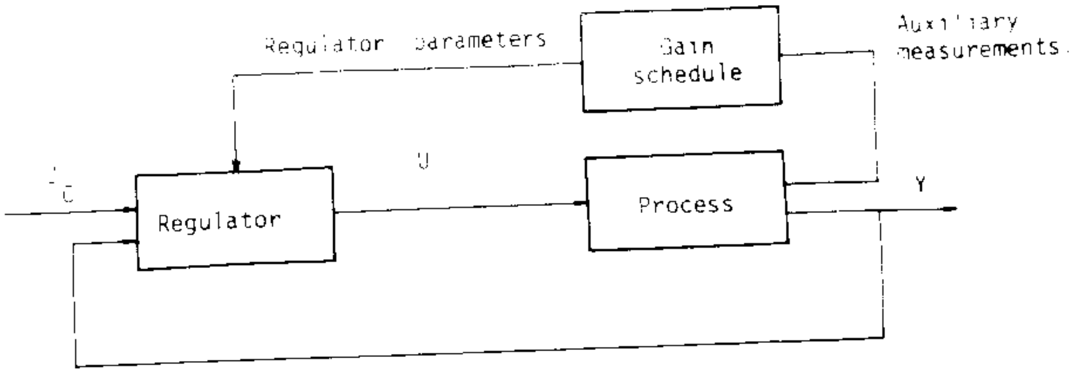

FIGURE (1.1) BLOCK DIAGRAM OF SYSTEM WHERE INFLUENCES OF PARAMETERS VARIATIONS ARE REDUCED BY GAIN SCHEDULING.

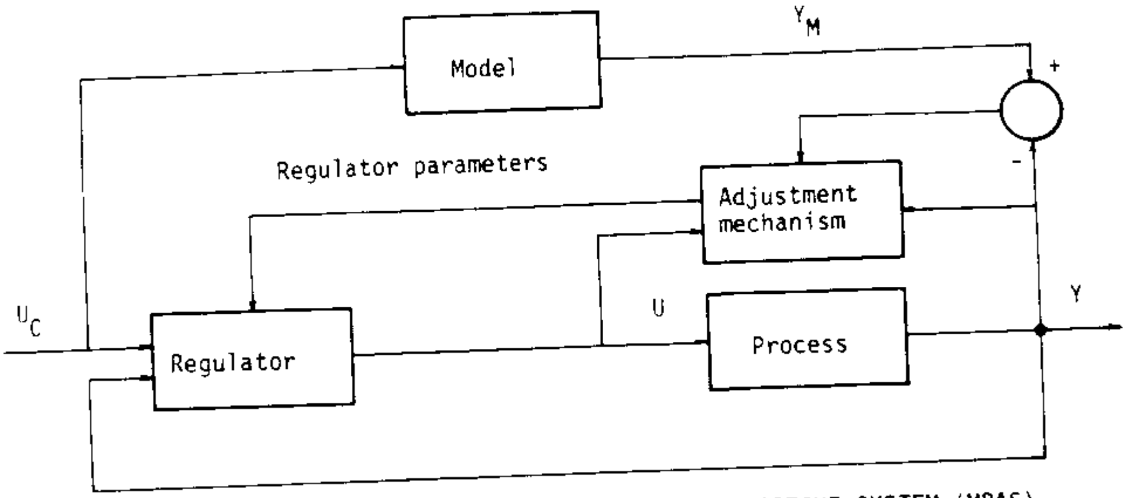

FIGURE (1.2) BLOCK DIAGRAM OF MODEL REFRENCE ADAPTIVE SYSTEM (MRAS).

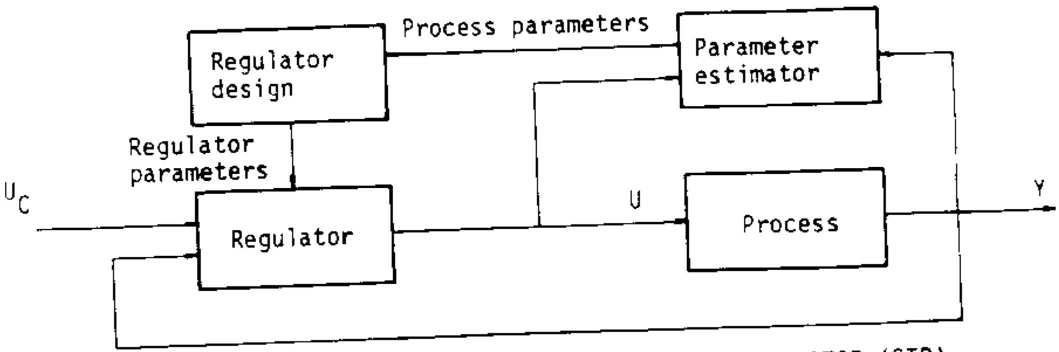

FIGURE (1.3) BLOCK DIAGRAM OF A SELF TUNING REGULATOR (STR).