UNIVERSITI PUTRA MALAYSIA

# MODELLING AND CONTROL OF LIQUID LEVEL SYSTEM

MARIZAN YAACOB

FK 2001 4

# MODELLING AND CONTROL OF LIQUID LEVEL SYSTEM

By

**MARIZAN YAACOB**

**Thesis Submitted in Fulfilment of the Requirement for the**
**Degree of Master of Science in the Faculty of Engineering**
**Universiti Putra Malaysia**

**October 2001**

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

# MODELLING AND CONTROL OF LIQUID LEVEL SYSTEM

By

**MARIZAN YAACOB**

**October 2001**

**Chairman:** **Samsul Bahari Mohd Noor, Ph.D.**

**Faculty:** **Engineering**

Control system modelling is difficult and delicate process. In most cases, the model cannot be obtained directly from the plant due to the complexity of the system components or the internal structure of the system is not sufficiently understood to allow analytical formulation of equations. On the other hand, the model can be proposed by investigating the dynamic characteristics of the system experimentally.

In this study, a model of a liquid level system is to be derived. The experimental data was obtained by applying a step input and measuring the output response of the system. A transfer function was estimated by using curve fitting technique. This estimated model has been refined by tuning the parameters e.g. gain, time constant, natural frequency and damping ratio.

Control design has also been carried out based on the model obtained through simulation. PD control has found to be superior compared to PID.

The same parameter settings of the controllers was applied to the real plant and performance of the system under PD control was satisfactory. This also proved that the model derived was a good estimate of the real plant and it can be used for further control design.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai
memenuhi keperluan untuk ijazah Master Sains

# PERMODELAN DAN KAWALAN PADA SISTEM ARAS CECAIR

Oleh

**MARIZAN YAACOB**

**Oktober 2001**

**Pengerusi:** **Samsul Bahari Mohd Noor, Ph.D.**

**Fakulti:** **Kejuruteraan**

Permodelan sistem kawalan adalah susah dan prosesnya adalah rumit. Dalam kebanyakan kes, model tidak dapat diperolehi secara langsung daripada loji disebabkan kekompleksan komponen pada sistem atau struktur dalamannya tidak diketahui sepenuhnya bagi membenarkan analisa perumusan persamaan. Sebaliknya, model boleh dicadangkan dengan menyelidiki cici-ciri dinamik suatu sistem secara eksperimen.

Dalam pengajian ini, model bagi sistem aras cecair yang akan diterbitkan. Data eksperimen diperolehi dengan melaksanakan masukan langkah dan mengukur sambutan keluaran daripada sistem. Rangkap pindah dikira dengan menggunakan kaedah padanan lengkuk. Model anggaran ini di perbaiki dengan melaraskan parameter seperti gandaan, pemalar masa, frekuensi tabii tak teredam dan nisbah redaman sistem.

Rekabentuk kawalan juga dilaksanakan berdasarkan model yang diperolehi, iaitu melalui simulasi. Kawalan PD didapati lebih baik berbanding PID.

Parameter yang sama dari kedua-dua pengawal kemudiannya digunakan pada loji asal dan prestasi sistem dibawah kawalan PD didapati memuaskan. Ini membuktikan bahawa anggaran yang bagus telah dibuat dimana model yang diterbitkan merupakan penghampiran daripada loji asal dan ianya boleh digunakan selanjutnya untuk rekabentuk kawalan.

# ACKNOWLEDGEMENTS

First and foremost, I would like to express my utmost gratitude to my project supervisor Dr. Samsul Bahari Mohd. Noor, Prof. Madya Ir. Dr. Norman Mariun and Dr. Sinan Mahmod for their invaluable guidance, constructive suggestions and encouragement throughout this project.

Lastly, I would like to thank my husband and family for their never ending love, patience and support which has enabled me to complete the project successfully.

# TABLE OF CONTENTS

Page

**CHAPTER**

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| $t$ | The independent variable time |
| $x(t)$, $w(t)$, $y(t)$, $c(t)$ | variables which are functions of time |
| $X(s)$, $W(s)$, $Y(s)$, $C(s)$ | variables which have been transformed into the $s$ domain. |
| $\tau$ | Time constant |
| $\zeta$ | Damping factor |
| $\omega_n$ | Undamped natural frequency |
| $p_1$, $p_2$ | Poles of transfer function |
| $z_1$, $z_2$ | Zeros of transfer function |
| PI | Proportional + Integral controller |
| PD | Proportional + Derivative controller |
| PID | Proportional + Integral + Derivative controller |

# CHAPTER 1

# INTRODUCTION

## 1.1 General Overview

The project title is modelling and control of level control system. This project is involved in controlling the water level in process control system. The process control is applied using real system RT210 Process Control Rig, G.U.N.T Control Technology Trainer. Measurement data acquisition and control is implemented by a software package which permit simulation of various type of controllers (P, PI and PID controllers, two point and three-point controllers).

The approach of this project is to observe the behaviour of the system in its normal working environment by introducing test signals. A model can be proposed from the observations of the output behaviour by following several steps of modelling methods. The time domain is the natural way to look at the behaviour of such systems since this is how to see the response of real systems. The experimental data of the system is obtained in real time sampling. The data is displayed as a measured response and is analysed in order to specify a mathematical model of the system. The measured response is compared with the response from a range of mathematical models using the Matlab program as a computer aided analysis. The model with the closest fit can then be chosen to represent the real system of process control system.

Matlab program is an alternative approach to model the system in the form of computer simulation. With a model it is possible to apply different signal and disturbances without worrying unduly over the system blowing up or causing physical harm. Indeed, modification can be carried out when a new setting parameters is found to work successfully, it then can be tried out on the actual system with a much greater degree of confidence. Hence, system performance can be investigated within and outside the expected operation range, thus any problem areas or improvement possibilities can subsequently be taken care as the actual system is concerned.

Another approach of this project is introducing the controller to the process control system. In order to analyse a system in terms of controller, a basic assumption is that we already have in our possession an accurate mathematical model of the system. The model estimation must be the closely approximated to the real system. Controllers are cascade control devices and they are inserted into an existing control loop to form part of forward gain of the control system. These devices are widely used in process control system and are usually employed as a part of the control circuitry on process control valves and hydraulic actuators. Controller contain three terms which are proportional, integral and differential is referred to as PID controller. The coefficients of PID controller can be found using the pole placement or Ziegler-Nichols methods. Once the controller coefficients have been finalised, the compensation term will be sorted out within this stage of the analysis.

## 1.2 Objective of This Work

Rosenbrock [1] discover that the problem of determining the transfer functions is a central one in control theory and it is especially important as far as computer aided design of linear control system is concerned. This problem has been attempted previously using pure numerical methods by Laub [2] and efficient algorithms for numerical computations of transfer functions at some discrete points on the imaginary axis have been designed. Although these algorithms are useful in many applications, analytical expressions for the transfer functions are often desirable because they contain the most complete characterisation of linear time-invarient systems. They allow for the numerical evaluation of the transfer functions and their derivatives at many points in the complex plane. Kailath [3] express that analytical transfer function can be useful in the investigation of controllability, observability and stability of control systems.

The objective behind this project is to find the model which represent the dynamic characteristics of the actual system. Chan [4] explained that the dynamic model of the control system is difficult to obtain, especially by analytical means. On the other hand, experimental data from this system is readily available. Chotai [5] and Rogers [6] had been developed a design technique based on experimental data to circumvent the problem. Franklin [7] discussed several reasons for using experimental data to obtain a model of the dynamic system to be controlled. Thus a model derived from transient response data can be reliable for designing the control system. Therefore the modelling technique based on experimental data is applied in this project in order to find the dynamic model of level control system. The dynamic model represents the dynamic sensitivity of a system which contains all the information concerning the dynamic behaviour of the system.

The step associated with a system modelling effort include [8]:

1. to evaluate the output response of system and identify the system order,
2. to identify the transient solution of a response function,
3. to use numerical approximation methods in system analysis to find the estimation transfer function,
4. to apply the Laplace transformation in the analysis of nth-order exponential equations,
5. to perform numerical analysis with the aid of the computer (calculation and using Matlab program),
6. to determine the physical significance of the roots of a characteristics equation for a system i.e. location of poles and zeros,
7. to determine the significance of the damping ratio $\zeta$ for a system in term of system behaviour,
8. to maintain system performance,
9. to apply PID controller to the system,
10. to test the ranges of parameter value of PID controller,
11. to achieve the desired output with minimal or no fluctuation,
12. to achieve maximum steady state-accuracy or minimum steady-state error, and
13. to determine minimal settling time.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 System Identification

The method is based on calculating the coefficients of the transfer function from data obtained from measurement on the data input and output. All these procedures require that the order of transfer function be assumed. The methods may be based on the frequency response, step response, the response to a rectangular pulse, or the response to a more general input. Generally, the methods can be considered to be a type of curve fitting, where the assumed transfer function is fitted to the available data in some optimal manner. These results in the "best" fit of the transfer function to the data but not necessarily result in a good model. For example, second order transfer function can be fitted to the input-output data of a highly nonlinear physical system. The result is a best fit of the transfer function to the data, but in this case the best fit is not good enough. Hence these methods, as with all system modelling techniques, must be used with great care [9].

Schwarzenbach [10] described about the system identification. A system of known transfer function, the response to a given forcing function can be evaluated. Where a system component is available for experimental testing the converse process can be employed in order to confirm the form of a theoretically derived transfer function, and to determine or confirm numerical values for the parameters, or alternatively, for a so-called ‘black box’ system where governing equations are not known, to derive representative transfer function. The process is one of subjecting the components to, say, a step change of input, recording the resultant output response, and by a process of curve fitting determining a transfer function which would yield this response.

If the response of a component to a step change of input exhibit any overshoot, with or without subsequent oscillation, or if the maximum slope of the output response occurs later than the time of application of step change, then the transfer function must be higher order than first. Attempt should be made to see whether a second order transfer function would give a close fit to the response curve obtained experimentally. Response testing of a practical system component can give a useful indication about linearity. The component can be considered linear provided the shape of the response curve resulting from a step change of input is not affected significantly by variation of the step size [10].

When concerned with dynamics systems it is of interest to know how the output of the system will change as a result of specific types of input change. On the basis of some appropriate criterion, an assessment can be made of whether or not the system behaviour is satisfactory and, if not an attempt made to improve the response by realisable modification to the system. With practical systems the exact form of the input excitation function may be known in advance, but most frequently the input will vary in a somewhat random and hence largely unpredictable manner (such would be the case where the ambient temperature is a significant input variable for the process plant or heating systems) [10].

## 2.2 Obtaining Model from Experimental Data

There are several reasons for using experimental data to obtain a model of the dynamic system to be controlled. In the first place, the best theoretical model built from equations of motion is still only an approximation of reality. Sometimes, as in the case of very rigid spacecraft, the theoretical model is extremely good. Other times, as with many chemical processes such as papermaking or metalworking, the theoretical model is very approximate. In every case, before the final control design is done, it is important and prudent to verify the theoretical model with experimental data.

Secondly, in situations where the theoretical is especially complicated or the physics of the process is poorly understood, the only reliable information on which to base the control design is the experimental data. Finally, the system is sometimes subject to on-line changes, which occur when the environment of the system changes. Examples include when an aircraft changes altitude or speed, a paper machine is given a different composition of fiber, or nonlinear system moves to a new operating point. On these occasions, the controller needs to be "retune" by changing the control parameters. This requires model for a new conditions, and experimental data are often the most effective, if not the only, information available for the new model. There are four kinds of experimental data for getting the model [7]:

1. Transient response, such as comes from an impulse or a step.
2. Frequency response data, which results from exciting the system with sinusoidal inputs at many frequencies.