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DESIGN OF PID TUNING GAIN SCHEDULING TECHNIQUE FOR TEMPERATURE CONTROL SYSTEM

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ABSTRACT

In this thesis, a PID controller is designed to control the performance of the process temperature control system. The designed PID controller is applied in the process of temperature control system by using fuzzy gain scheduling technique to improve the performance of transient response of the temperature control system. MATLAB/Simulink software is used in order to design the PID controller and thus, to obtain the analysis of the performance of the transient responses for the temperature control system. As a result, the simulation from the MATLAB shows the temperature control system performance which is in transient response analysis, parameter variation and statistical analysis. The transient response analysis gives the results in term of percentage overshoot, rise time, settling time and steady-state error. Next, to get a better performance in the temperature control system, the fuzzy gain scheduling technique is applied until the desired temperature without a disturbance is achieved. From this, it has been found that PID controller tuned by the fuzzy gain scheduling technique gives the best performance compared to PID controller using Cohen-Coon and Ziegler-Nichols method. It is because the rise time and settling time of the system from fuzzy gain scheduling is faster compared to the other two methods which is 0.004ms and 0.013ms respectively.

ABSTRAK

Dalam tesis ini, pengawal PID direka untuk mengawal prestasi dalam sistem proses kawalan suhu. Pengawal PID yang direka digunakan dalam proses sistem kawalan suhu dengan menggunakan teknik keuntungan penjadualan kabur untuk meningkatkan prestasi sistem kawalan suhu. Perisian MATLAB/Simulink digunakan untuk mereka bentuk pengawal PID dan justeru itu, mendapatkan analisis prestasi untuk sistem kawalan suhu. Hasilnya, simulasi dari MATLAB menunjukkan prestasi sistem kawalan suhu yang di analisis dalam bentuk sambutan fana, perubahan parameter dan analisis statistik. analisis sambutan fana memberikan hasil dalam bentuk peratusan terlajak, masa naik, menetap masa dan ralat keadaan mantap. Seterusnya, untuk mendapatkan prestasi yang lebih baik dalam sistem kawalan suhu, teknik keuntungan penjadualan kabur digunakan sehingga suhu yang dikehendaki tanpa gangguan dicapai. Melalui teknik ini, telah terbukti bahawa pereka PID yang direka oleh teknik keuntungan penjadualan kabur memberikan prestasi yang terbaik berbanding pengawal PID menggunakan kaedah Cohen-Coon dan kaedah Ziegler-Nichols. Hal ini adalah kerana masa naik dan masa penetapan sistem daripada penjadualan keuntungan kabur yang lebih cepat berbanding dua kaedah lain iaitu 0.004ms dan 0.013ms.

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LIST OF ACRONYMS

1. PID : Proportional Integral Derivative
2. RTD : Resistance Temperature Detector
3. SE : System Stored Energy
4. LPV : Linear Parameter Varying
5. GSBC : Gain Scheduling Backstepping Control
6. PLI : Power-Line Inspection
7. EML : Equilibrium Manifold Linearization
8. SI : System Identification
9. EM : Electromagnetic
10. GUI : Graphical User Interface
11. ADC : Analogue to Digital Converter
12. PV : Photovoltaic

CHAPTER 1

INTRODUCTION

1.1 Introduction

There are many types of process that implement the gain scheduling technique into their system such as temperature control system, aircraft system, water level control system and others. The temperature control system are widely used in the researches as temperature is one of the most important parameter that usually influenced the process of a certain system. The control of temperature is important for the performance of the end product. The characteristics of the temperature control systems in the industry mainly have long delay time and large time constants. Because of the long delay time and large time constant, the difficulties of the temperature control system is increasing [1]. In order to obtain a good performance of the system, a gain scheduling technique is implemented into the system.

The gain scheduling technique is basically used for non-linear systems where the control system is decomposed into a several linear sub-parts. Gain scheduling technique had been defined as a linear parameter varying feedback regulator whose are changed as a function of operating conditions. This technique occurred in the early 1950s when the researchers use this technique in the design of autopilots for high performance aircraft [2]. It can also alter the linear controller parameters in a non-linear mode depend on the process state and scheduling variable [3]. The main ability of the gain scheduling technique is able to design the linear sub controllers based on a set of linearized model of the non-linear plant [4]. So, the gain scheduling technique is one of the most popular technique to design non-linear control and has been successfully implemented into several systems [5].

It is because the gain scheduling technique has many advantages as most of the researches apply this technique in order to obtain a high performance of the process control. This technique is scheduled along with the time-varying parameters and can adjust the parameters to adapt the changes in real time environment [6]. Usually, the use of this technique is to allow a high performance system across the scheduling parameter interval. Many approaches are designed for gain scheduling such as interpolation, Youla parameterization and fuzzy logic [7]. So, each of the approaches are suitable for a certain type of process control.

In this project, a temperature control system is considered in the research study. So, in order to implement the gain scheduling technique into this system, a mathematical modelling is derived based on the model of the system. The transfer function of the system is obtained from the system identification tool to compare with the transfer function of the real-time experiment where Simulink/MATLAB is used. The model diagram of the process system is in the open-loop system. A Microbox 2000/2000C is used to interface the data of the system into the software so that the transfer function can be estimated by using system identification tool.

1.2 Objectives

1. To identify the transfer function of Lab Volt Process Control Trainer by using System Identification Tool.
2. To design a PID controller by tuning the PID gain using fuzzy gain scheduling technique.
3. To analyse the transient response of the temperature control system based on the implementation of PID controller using fuzzy gain scheduling, Cohen-Coon and Ziegler-Nichols technique.

1.3 Motivation

The main motivation of doing this project is to design the PID controller of the temperature control system until a good result of performance is obtained. As the Lab-Volt Process Control Trainer was used as the temperature control system, the plant that mainly used as a trainer in a laboratory is always non-effective. It is because the trainer has been used as a trainer for the students for a long time. So, the functions of the trainer may be not achieve the requirements. Therefore, by doing this project, a PID controller can be easily designed just by using the MATLAB software than using the manual designed of PID controller. It will resulting in a good performance of the temperature control system.

1.4 Problem Statement

As the temperature control system used which is Lab-Volt Process Control Trainer is not that effective, it is very hard to carry out since its behaviour can change during the process. Besides that, it is shown that the parameter of the system which is temperature is always changeable. Besides that, a fixed gain PID controller cannot give a satisfactory results as the controller used is less efficient and this will lead to instability of the system. And lastly, it has a hard way to obtain the transient response graph for the performance without using any software.

So, to overcome the problems occurred above, a PID controller is implemented into the system to give a good performance of transient response of the system. As a fixed gain PID controller cannot gives a satisfactory results, the gain scheduling technique is applied for the changing of the parameters until the desired requirements are met. Last but not least, the system is then implemented into the MATLAB/Simulink software to obtain the transient response of the system so that the system can be observed easily and it also can varying the parameters until the desired performance is obtained.

1.5 Scopes

This project is divided into two parts which are hardware and software. For the hardware part, the plant used is Lab-Volt Process Control Trainer which acts as the temperature control system. The sensor used to detect the radiator temperature is thermocouple and the transmitter is used to measure the reading of the temperature. The Microbox 2000/2000C acts as an interface of the system to send the data from the plant to the PC host. The Ethernet cable is connected between the Microbox and the PC host. For the Simulink to receive the data from the plant, the plant acts as xpctarget.

For the software part, the MATLAB software is introduced. The data received from the plant is stored in the workspace of the software in term of timelog and outputlog. The switch used is varied with input 0 until 5V. The analog to digital converter sampling time is 0.001s as the frequency of the Microbox is 1 kHz. The analog to digital converter (AD1) is connected to the temperature transmitter output while the digital to analog converter (DA11) is connected to the control input.

Besides that, the system modelling of the plant is important for the transient response of the system to be obtained. Therefore, a transfer function is needed. To obtain the transfer function of the plant, the System Identification Tool is used. The purpose of this identification is to determine the characteristics of the control process. The input and output data collected from the experiment is used where a few estimation are made regarding the structure of the plant model [8].

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A temperature control system has been used in this project to analyse the performance of the system. A Lab-Volt Process Control Trainer is used to undergo this project to obtain the performance of the temperature control system. In this project, a PID controller must be designed by using gain scheduling technique to implement it into the plant. The PID controller is designed to improve the transient response and the steady-state error of the system.

The parameters required are the voltages and temperatures. These parameters is a must in order to obtain the relationship between voltage and temperature that occurs in the plant. After that, the open-loop control system input and output data is imported into the System Identification Tool to obtain the modelling system transfer function.

This project requires several equipment such as Lab-Volt Process Control Trainer, Microbox 2000/2000C and MATLAB software. In this literature review, the description of each equipment are properly described.

2.2 Temperature Control System

A temperature control system widely used in the industrial area and many researches have been done in order to improve the performance of the control process. A temperature control system is basically divided into two parts which are automatic and manually control system. The system is called automatic when the when there is a sensor used to sense the temperature while the system is called manual when the system reads the temperature and adjusts the heat and cooling input in the direction of up and down until the temperature reach its desired value.

A research has been conducted about the industrial furnace temperature process control. The furnace system is divided into two systems which are the main controlled variable and sub controlled variable. The main variable shows the temperature of raw material while the sub variable shows the temperature of the hearth in the furnace. The disturbances that involved in this system are the flow of the raw material and temperature of the material at the inlet [9]. There also another experiment which is conducted in the process furnace control system. This experiment is about the disturbances involved that effect the performance of the temperature in the furnace control system. The temperature control system of process furnace also consists of two parts which are branch temperature balanced control to prevent coking in tubes and outlet temperature control to provide appropriate temperature for crude installation [11].

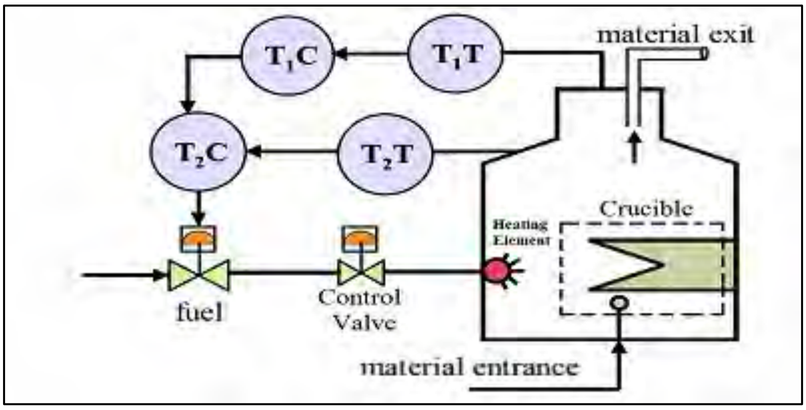

Figure 2.1: The Furnace Temperature System [11]

Besides that, there is another research of temperature control system for cement raw meal calcination process. It is a process where raw cement materials are processed and transformed into clinker after preheating, decomposition and calcination. The main components involved in the calcination process are calciner which are used to decompose the raw meal and fuel combustion and preheaters that are used to heat raw meal [10].

Another research of temperature control system has been conducted using virtual air temperature oven. The oven consists of resistance temperature detector (RTD), thermocouple and the heating element. The sensors acts as a feedback to measure the air temperature in the oven. The controller is used to control the heater power through a selector either in time proportional relay control or current continuous in a unit of mA [12].

Figure 2.2: The Air Temperature Oven [12]

Therefore, for this project, Lab-Volt Process Control Trainer which consists of the radiator temperature process is used. This is called an automatic temperature control system as sensor is used in this system and the accuracy of the value of the parameters is a must. Besides that, the temperature changes are quite fast in order to obtain the relationship between the temperature and voltage.

2.3 Parameters

In all process control system, parameters need to be taken into consideration as the parameters involved has a relationship to obtain the performance required. For an example, in the blade of wind turbine process, the length takes the important rule in the making of the blade. It is because when the length increases, the weight also increases. The vacuum is used to reduce one side pressure of the blade body and the heating process takes place to increase the blade strength [13].

In the temperature control of catalytic cracking process, the mathematical modelling involved are riser model and regenerator model. In the riser model, the mass and the mass flow rate of reactor product and spent catalyst are involved in the calculation to obtain the reactor bed temperature. The regenerated catalyst feed rate acts as the input. The heat of reaction and combustion are constant. For the regenerator model, the mass and the mass flow rate of flue gasses, air temperature and air rate are used to calculate the regenerator temperature [14].

A research has been conducted on emulated inertial response from wind turbines where the parameters involved in power system modelling are infeed trip size, load levels, system stored energy (SE) and governor droop settings. The system comprises of variable speed and fixed speed wind plant. Therefore, the load conditions are varied for instantaneous wind penetration levels of 20, 40 and 60% [15].

In the decoupled temperature control system, the temperature of the plastic in injecting-moulding machine is taken into account because it decides the quality of the plastic products. The input voltage has strong influences to every output. Therefore, the relationship of voltage and temperature has huge function in order to obtain the transfer function with different time delay [16].

In this paper, the parameters involved has been identified which are voltage and temperature. This relationship is taken into consideration in order to do calibration of the Simulink for the display block diagram displays the value of temperature. This is because, when the system is running, the data saved in the workspace in the MATLAB will be temperature instead of the voltage.

2.4 Controllers

A controller is very important in all types of control systems. The function of the controller is to improve the performance of each system. It improves the performance of the systems in terms of percentage overshoot, rise time, steady-state error and settling time. It is a must to have the controller in the system to improve the transient response and steady-state error of the system.

In one of the researches of temperature process that have been done, a traditional PI controller has implemented in the system to improve its performance, but it produces high overshoot and the design procedure seems complex. Therefore, the usage of intelligent controller has been proposed because it offers a better overshoot and settling time and thus increases the robustness of the system [17]. There is also another system which use direct synthesis method based PI controller in control level of a single conical tank system. The PI controller used takes a longer time for the system to reach the set point. Thus, the performance of the system is then compared with the use of the adaptive control based PI controller and it shows that the controller tracks the set point faster with less rise time [18].

An experiment of tuning methods for PID controller parameter of DC motor has been conducted. The PID controller has been designed using three methods which are Ziegler-Nichols method, Simulink Response Optimization Toolbox and Fuzzy Gain Scheduling. Based on the three methods used, it has been found that the fuzzy gain scheduling based PID controller gives efficient position of DC motor compared to the other two methods [19]. Same method is used in controller design for the position control of a DC motor. In this research, the use of sliding mode controller gives off high robustness against uncertainties but it can lead to chattering phenomena that can harm the plant. Therefore, in order to enhance the sliding mode controller performance, PID tuned by fuzzy logic is used. The result shows that the chattering has been avoided [20].

In another research of temperature control, the PID controller based Scr Control system is used. The PID controller is used in order to eliminate the contactor-based ON/OFF control for the heating applications. This is because, the ON/OFF controller consumes large consumption and gives damages to the equipment. So, the PID controller based Scr control system replaced the old controller because it ensures a longer life period for the equipment and it also reduces the energy losses [21].

Literally, the adaptive or intelligent control based controller gives a better performance compared to direct synthesis method based PI/PID controller. Usually, the direct synthesis method or traditional method takes much time to reach the set point. Thus, the use of intelligent based controller are widely used in the industry as it gives minimum rise time, quick settling time response and tracks the set point faster [22].

2.5 Gain Scheduling

The gain scheduling technique is basically used for non-linear systems where the control system is decomposed into a several linear sub-parts. This technique is used when it is possible to find the parameters which related well with the changes of the process behaviour. Many efforts have been devoted to develop methods of gain scheduling to reduce the time spent on optimizing the choice of controller parameters.

A research has been conducted on fuzzy gain scheduling of PID controller that is implemented on real time level control. In this system, non-adaptive conventional PID controllers do not provide desired response. However, using fuzzy algorithm is not as easy as defining PID controller gains. Therefore, the advantages of both fuzzy algorithm and PID controller are mixed to form a fuzzy-PID gain scheduling controller that satisfies the response parameters for the level control system [23].

There is also another research has been made where the paper addresses the LPV gain scheduling method for controller design of turbo fan jet engines. This method used a process description of linear parameter varying system. The mapping of linear controllers are not necessary but the transformation of non-linear process model to a LPV system is a hard task. Therefore, most LPV method use modern techniques such as H_2 or $H\infty$. It is because modern techniques has resulting a stable controller and the performance is guaranteed [24].

In another research paper, a gain scheduling backstepping control (GSBC) has been proposed for the motion balance adjusting of the power-line inspection (PLI) robot. As usual, the function of gain scheduling is to convert the non-linear dynamic model of the PLI robot into a linear model. The linear model is then transformed into an equilibrium manifold linearization model (EML) using a scheduling variable. This method extends the operational area of the closed-loop system and overcomes the initial non-linearities of the model. The results show that the proposed GSBC technique proved the efficiency and feasibility [25].

As a conclusion, for this project, a fuzzy gain scheduling has been proposed to improve the performance of the temperature control system. This type of technique determines the controller parameters of the PID controller and it will generate the control signal and it gives a better performance of the system than using the PID controllers with fixed parameters [26].

2.5.1 Fuzzy Gain Scheduling

The fuzzy logic gain scheduling technique is implemented in this project. Based on previous research, fuzzy logic scheduling consisted of two inputs and three outputs and every research used different types of output's tuning. There was also some research that tuned two outputs to design PI or PD controller.

In the research paper of subspace predictive controller, the fuzzy logic gain scheduling was implemented into the system to update the subspace predictive controller gains. The output parameters used were controller gains, K_e and $K_{\Delta ep}$ and proportional gain of the current, $K_{\Delta up}$. The SPC gains were tuned by applying fuzzy logic rules. Therefore, the simulation result showed that the proposed fuzzy gain scheduling with SPC gave more robust tracking performance compared to the conventional SPC [27].

Meanwhile, in order to improve the power system transient stability by PV farm, the PV farm was equipped with a fuzzy gain scheduling of PID controller for transient stabilization of a multimachine power system. This controller was used to control the PV inverter, so that the PV output can stabilize the transient power when the faults took place. This controller tuned the parameters outputs of value K_p, K_i and K_d [28].

In this project, the parameters outputs that had been tuned were K_p, K_d and α. The value of K_i was calculated by using the value of α that has been tuned by the fuzzy logic controller. Some equations were involved in this technique.

2.6 Lab-Volt Process Control Trainer

Lab-Volt process control trainer is used as a plant that is mainly used in the laboratory. It is a flexible teaching and demonstration tool for the students of control electrical engineering as it shows a wide range of control engineering principles. The process control trainer is designed to perform the temperature process control. This plant consists of electrical driven fan which induces air flow through a duct. The incoming air is heated by the heater that is placed near the fan. The light of the heater will turn on when there is overheat occurred. The heater power is obtained by using a linear amplifier. The output power of the plant is proportional to its input voltage [29].

Besides that, this plant also comes with a built in proportional controller which are PID controller that can be used in order to improve the performance of the required process control. This plant also can be interfaced with other devices to implement external control in order to obtain accurate results of the performance of the control system.

In this project, Lab-Volt process control trainer is connected to the Microbox 2000/2000C to obtain the accurate data of the system. The control input, output of the transmitter and the ground are connected to the Microbox for them to transfer the analog signal into digital signal to the MATLAB software.

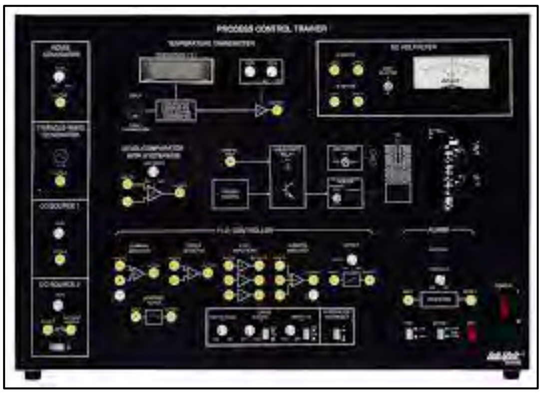

Figure 2.3: The Lab-Volt Process Control Trainer

2.7 Thermocouple

Thermocouple is a sensor that measure the reading of the temperature with an electric output signal. It consists of two dissimilar conductors in contact that produce a voltage when heated. The size of the voltage is depend on the difference of temperature of the junction to the other parts of the circuit. This sensor is widely used for measurement and control and can also be used to convert temperature gradient into electricity [21].

There are many types of thermocouples which are type J, K, T and E for base metal and type R, S and B for noble metal. Commercial thermocouples can measure a wide range of temperatures and are inexpensive. The main limitation of the thermocouples is accuracy because the system errors of less than one degree Celsius can be difficult to achieve.

In this project, the J type thermocouple is used as it is the most common types of thermocouples. The thermocouple sensor is used because of their low cost, high temperature limits and wide temperature ranges.

2.8 Temperature Transmitter

The temperature transmitter is one of the part that involved in the Lab-Volt Process Control Trainer. Temperature transmitter is an electrical instrument that interface the temperature sensor used which is thermocouple to a measurement or control devices. It converts the input signal from the thermocouple and then transmits the output signal to the control device. The reading of the temperature from the plant will be displayed on the process control trainer by using this temperature transmitter.

2.9 Microbox 2000/2000c

Microbox is a microcontroller and acts as a XPC target machine. This component is machine device used to interface the hardware model with the MATLAB software. It is a solution for testing, prototyping and developing real time systems using standard PC hardware for running real time applications. It also supports all PC hardware such as video, mouse and keyboard. This Microbox can run real-time modelling and simulation of control systems and hardware in the loop testing [30].

Figure 2.4: The Microbox 2000/2000C

This hardware allows sampling time of 0.001s which is 1 kHz. It is a driver that communicates between input and output devices on the target PC and the temperature control system. It enables the interaction between the real-time application and the plant. Besides that, it contains a code that runs on the target hardware for interfacing with input and output devices such as analog-to-digital converters, encoders, digital signals and communication parts.

These driver are implemented as block diagram in the SIMULINK of the MATLAB. The xPC target works with the code generated from the SIMULINK and a C compiler to build the real-time target application. The real-time target application represents the plant of the temperature control system and it can run on the PC once it is downloaded.