ELECTRONIC THROTTLE BODY TUNING USING NON-LINEAR PID CONTROLLER

DHARMAWAN BIN DHARHAM

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DECLARATION

I declare that this project report entitled “Electronic Throttle Body Tuning Using Non-Linear PID Controller” is the result of my own work except as cited in the References

Signature : ....

Name : Dharmawan bin Dharham

Date : July 2017

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature : ....

Supervisor's Name : Mr. Faizul Akmar bin Abdul Kadir

Date : July 2017

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DEDICATION

Special dedicate to my wife, father and mother who never stop pray for me and give morale support. This dedication also for my supervisor who never give up to advise, teach and guide me to complete this Final Year Project. Not to forget my friends who always lend a hand during this project and during period of completing the report as well as lecturers and most of all Almighty Allah who gives me good health as well as strength to go through this period. All the effort during this program will be nothing without help from all of you.

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ABSTRACT

Electronic throttle body (ETB) is one of the most important components in the gasoline engine system of the vehicle. It serves to regulate the amount of air flow into the engine during the induction stroke with the proper ratio. Even though the ETB have been used in the automobile industry for a long time, there still exist some difficulties in this technology in controlling the electronic throttle valve that causes the air and fuel ratio is not quite right as needed. The difficulties that affecting the ETB performance is attributed from the discontinuous nonlinear of the spring that force the valve plate to return to its original position and also the non-linearity that lies inside the system such as stick-flip friction and gear backlash. In this project, the ETB will be tuned using the Nonlinear Proportional Integral Derivative (PID) controller. ETB model will be built up using Matlab software and then the tuning simulation process of ETB is carried out using conventional PID controller for angle of 30º, 45º, 60º, 75º and 90º. After that, the Nonlinear PID controller will built up and then the tuning process will conduct using the k_P, k_I , and k_D gain from a selected angle as a reference. Finally, the results of tuning simulation using a Nonlinear PID controller will be compared with the conventional PID controller to evaluate its performance.

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ABSTRAK

Badan Pendikit Elektronik (ETB) adalah salah satu komponen yang sangat penting di dalam sistem enjin kenderaan petrol masa kini. Ianya berfungsi untuk mengawal jumlah kemasukan udara ke dalam enjin semasa lejang masukan mengikut nisbah udara dan bahanapi yang betul. Walaupun ETB telah digunakan dalam industri automobil untuk masa yang lama, masih terdapat beberapa kesukaran dalam teknologi ini bagi mengawal injap pendikit elektronik yang menyebabkan udara dan nisbah bahan api tidak berapa tepat seperti yang diperlukan. Kesukaran yang menjejaskan prestasi ETB ini berpunca apabila berlakunya ketidaklinearan yang berlaku dari sifat spring yang menyebabkan injap plat ingin kembali kepada kedudukan asalnya, dan juga ketidaklinearan yang terjadi di dalam sistem ETB itu sendiri seperti geseran ‘stick-flip’ dan tindakbalas gear. Dalam projek ini, ETB akan ditala menggunakan Kawalan Proportional Integral Derivative (PID) Tidak Linear. Model ETB akan dibina menggunakan perisian Matlab dan kemudiannya proses simulasi penalaan ETB tersebut dibuat menggunakan kawalan PID konvensional bagi sudut 30º, 45º, 60º, 75º dan 90º. Setelah itu, Kawalan PID Tidak Linear pula dibina dan seterusnya proses penalaan bagi semua sudut tadi dilakukan menggunakan nilai gain k_P, k_I , dan k_D dari sudut yang dipilih sebagai rujukan. Akhir sekali, hasil dari keputusan simulasi penalaan menggunakan kawalan PID Tidak Linear ini akan dibandingkan dengan keputusan simulasi penalaan menggunakan kawalan PID konvensional untuk menilai prestasinya.

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Hopefully, this will not be the end of my journey in seeking for more knowledge. Thank you.

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TABLE OF CONTENTS

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LIST OF TABLES

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

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LIST OF ABBEREVATIONS

ETB	Electronic Throttle Body
DC	Direct Current
NPID	Nonlinear Proportional Integral Derivative
PID	Proportional Integral Derivative

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CHAPTER 1

INTRODUCTION

1.1 Background

The Electronic Throttle Body (ETB) is a very important component in engine system control the throttle valve opening angle for the purpose to regulate the amount of airflow into the engine meets the desired amount. The opening of the throttle valve is controlled by an electronic computing module (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Bai & Tong, 2014). For modern automobiles, ETB system is one of the important drive by wire systems. The ETB consists of a direct current (DC) motor, a motor pinion gear, an intermediate gear, a selector gear, a valve plate and nonlinear spring (Figure 1 and Figure 2) (Pan, Özguner, & Dağci, 2008).

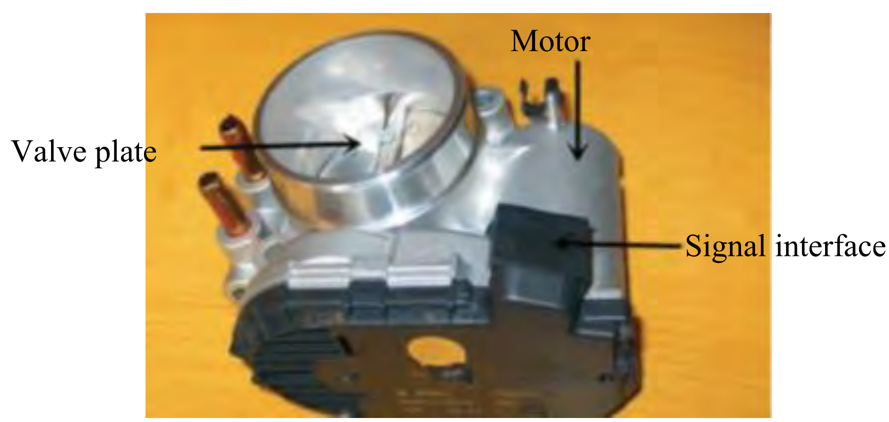

Figure 1.1: External view of ETB.

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Figure 1.2: Internal view of ETB.

Traditionally, the throttle plate is connected directly by wire to the accelerator. So the mass air rate controlled according to the driver demand. In this method, many internal and external conditions such as fuel efficiency, road or weather condition to determine the throttle plate angle are ignored. As a result, all this factor will negatively affect to the overall efficiency of the engine (Mercorelli, 2009).

To determine accurately the throttle valve opening angle, an electronic control module (ECM) is used to overcome the above deficiency. Electrical wire or fiber optic cable is used to transmit the gas pedal and the measured signal to the central processing unit. It determines the optimum reference opening angle and send the signal to the ETB to let the valve plate follow the signal by using a proper controller (Bai & Tong, 2014) ("4. Delphi_Drive_by_wire_2000-01-0556," n.d.).

By using the ETB, there are some problem occur in this system which make the controller design difficult. There are non-smooth nonlinearities including stick-slip friction, gear backlash, and a nonlinear spring. Furthermore, the controller design becomes more difficult because most of control algorithms assume that the uncertainty is smooth and/or satisfies the

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matching condition, while as the parameters of these non-smooth nonlinearities cannot be known accurately, the non-smooth and also unmatched parameter uncertainties inherently exist (Pan et al., 2008) (Di Bernardo, Di Gaeta, Montanaro, & Santini, 2010).

By using a back-stepping approach, proportional integral derivative (PID) controller is designed for matching uncertain systems and may be implemented in an unmatched uncertain system (Pan et al. 2008). It is designed for the electronic throttle valve with the back-stepping approach together with the feedback linearization technique (Ahmed AL-Samarraie & Khudhair Abbas, 2012). The purpose of proportional integral derivative (PID) controller is to ensure the valve plate follows the reference signal using continuous-time sliding mode concept by deriving a controller with an observer. It is capable of coping with the uncertainties in the mathematical model non-smooth nonlinearities, which exist in the control region and some unmodeled mechanical phenomena, as a reason to select this method (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Pan et al., 2008). The designed time-optimal controller achieves considerably faster transient, while preserving other important performance measures, like the absence of overshoot and static accuracy within the measurement resolution (Ahmed AL-Samarraie & Khudhair Abbas, 2012).

1.2 Problem Statement

Since the ETB consists of a direct current (DC) motor, a motor pinion gear, an intermediate gear, a selector gear, a valve plate and nonlinear spring, there exist multiple non-smooth nonlinearities including stick–slip friction, gear backlash, and a nonlinear spring, which make controller design difficult (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Pan et al., 2008).

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Due to the mechanical part moving in the ETB, certainly friction will occur. Friction is the motion resistance of the moving object relative to another. In ETB, it is a nonlinear phenomenon in which a force that produced by the resistance tends to oppose the motion of throttle plate such as coulomb, static, viscous, stribeck, etc. (Pan et al., 2008) (Conatser, Wagner, Ganta, & Walker, 2004). In this concept, static friction phenomena only have a static dependency on velocity and the coulomb friction is considered.

The typical feature of the electronic throttle valve includes a stiff spring, which is used as a fail-safe mechanism. When no power is applied, this spring act as a force to push the valve plate to return to the position slightly above the closed position, so that the small amount of air can be supplied into the engine in order to prevent a sudden lock of engine revolution while the vehicle is in motion when no control is available (Jiao & Shen, 2012). Moreover, the motion of the valve plate is limited between the maximum and minimum angles. These limited stops are realized by a highly stiff spring, ideally with infinite gain.

Due to the clearance formed between a pair of mounted gears, there exists backlash between gears where the gear backlash is another nonlinearity source in addition to friction and the non-linear spring.

All this factor affected to reach an ideal air fuel ratio (stoichiometric about 14.7:1) required by the engine especially when the drastically change to the velocity of the vehicle required by the driver. Therefore, the ETB which is controlled by the electronic control module need to do the tuning to achieve the desired throttle valve angle.

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1.3 Objective

The objectives of this project are as follows:

1. To develop an ETB model in MATLAB software.
2. To design a Nonlinear PID controller to obtain the desire throttle angle.
3. To compare the result with conventional PID.

1.4 Scope of Project

The scopes of this project are:

1. Study about ETB especially the parameter and its function. Also, study the problem that occurs in this system to achieve the desire throttle angle.
2. This project only focuses on tuning simulation.
3. Perform the simulation by using MATLAB software.
4. Model the ETB provide by (Pan et al., 2008) using MATLAB Simulink application.
5. Apply the model of non-linear PID controller by using MATLAB Simulink
6. Compare the result of conventional PID with the non-linear PID controller.
7. Conduct the various simulations for the different throttle opening angle such as 30º, 45º, 60º, 75º and 90º.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the previous well-known experimental and tuning method that has been performed in the field of electronic throttle body. However, some important explanation of this project will be explained first. A method for tuning electronic throttle body will describe in this chapter.

2.2 Electronic Throttle Body (ETB)

Now a day, throttle body system is no longer a foreign component in the automotive industry, but its use has become very popular and widespread. Electronic throttle body necessitates the use of an electric actuator motor because there is no mechanical linkage between the accelerator pedal and the throttle body. There are several reasons why electronic throttle actuation is preferable to a conventional throttle cable:

a. The electronic systems are able to control all of the engine's operation with the exception of the amount of incoming air.

b. Only the correct amount of throttle opening will receive by the engine for any given situation which ensured by using throttle actuation.

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c. The harmful exhaust emissions are kept to an absolute minimum and drivability is maintained and ensured by the optimization of the air supply. Finer control can be achieved because coupling the electronic throttle actuation to the adaptive cruise control, traction control, idle speed control and vehicle stability control systems. (“Automotive Applications of Sliding Mode,” n.d.)

The use of such a system has advantages over the conventional cable version by:

a. Make the system become simpler by reducing the number of moving parts by eliminating the mechanical element of a throttle cable and using with fast responding electronics. It requires minimum adjustment and maintenance.

b. Provides better response and economy because of the greater accuracy of data improves the drive ability of the vehicle (Goodwin, Graebe, & Salgado, n.d.).

However, by using the electronic throttle body, there are some problem occur in this system which make the controller design difficult. There are non-smooth nonlinearities including stick-slip friction, gear backlash, and a nonlinear spring. Furthermore, the controller design becomes more difficult because most of control algorithms assume that the uncertainty is smooth and/or satisfies the matching condition, while as the parameters of these non-smooth nonlinearities cannot be known accurately, the non-smooth and also unmatched parameter uncertainties inherently exist. (Conatser et al., 2004). A typical configuration of an ETB is shown in Figure 2.1.

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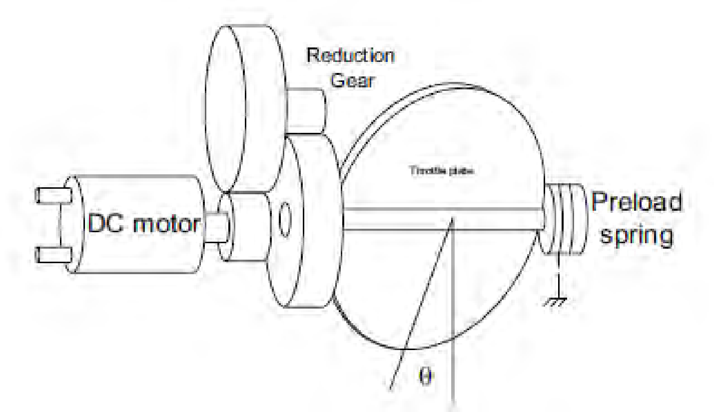

Figure 2.1: Electronic Throttle Body Schematic.

2.3 Nonlinearities

The nonlinearities, such as friction, nonlinear spring and gear backlash involved in the electronic throttle body system make the controlling of opening throttle valve angle and to realize a highly robust controller against uncertainties become difficult (Araki, n.d.), (Pan et al., 2008).

2.3.1 Friction

Friction is the motion resistance of the moving object relative to another. It is a nonlinear phenomenon in which a force that produced is tends to oppose the motion of throttle plate such as coulomb, static, viscous, stribeck, etc. Only the coulomb friction is considered in this work. Static friction phenomena only have a static dependency on velocity (Al-samarraie, 2012). The Coulomb friction model is demonstrated in the Figure 2.2 below.

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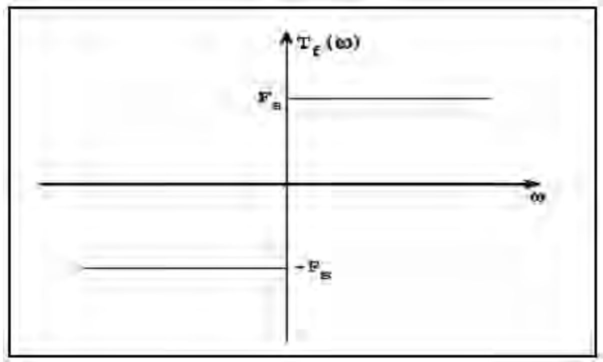

Figure 2.2: Coulomb friction.

Consequently, the Coulomb friction model mathematically is given by

$$T_f(\omega) = \begin{cases} F_{s,} & \omega > 0 \\ 0, & \omega = 0 \\ -F_{s,} & \omega < 0 \end{cases}$$

$$= F_{s,}\,\mathrm{sgn}(\omega) \qquad - \qquad (1)$$

where $F_{s,}$: is a positive constant (Ahmed AL-Samarraie & Khudhair Abbas, 2012).

2.3.2 Nonlinear Spring

Electronic throttle body component typically includes a stiff spring, which is used as a fail-safe mechanism. The purpose of this spring is to force the valve plate to return to the position slightly above the closed position when no power is applied. So that, when no control is available while the vehicle is in motion, the small amount of air can be supplied into the engine to prevent a sudden lock of engine revolution. Moreover, the motion of the valve plate is limited between the maximum and minimum angles. These limited stops are realized by a highly stiff spring, ideally with infinite gain. (Ma, Shao, & Yurkovich, 2005). The characteristic of the modelled spring is shown in Figure 3.3.

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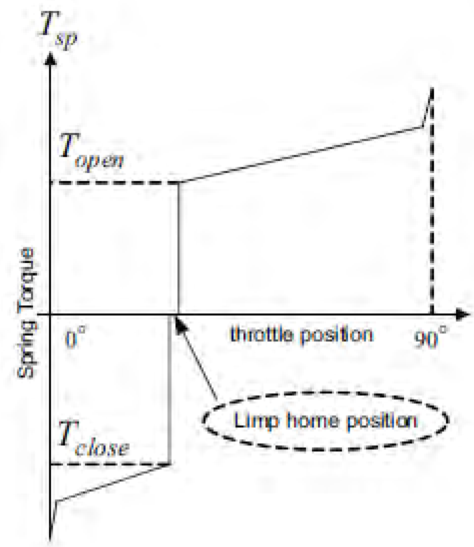

Figure 2.3: Nonlinear spring.

2.3.3 Gear Backlash

In addition to friction and the nonlinear spring, the gear backlash is another nonlinearity source due to the clearance formed between a pair of mounted gears. The error in profile, pitch, tooth thickness, helix angle, and canter distance, and run-out is the factors that affecting the amount backlash needs in the gear transmission system. The greater the accuracy the smaller the backlash needed. The way to reduce the gear backlash is by increasing the centre distances between the gears (Circle, n.d.). The gear backlash between two gear shown in figure 2.4. When writing the throttle valve mathematical model the nonlinearity coming from backlash phenomenon is ignored in this work. (Buckbee & Buckbee, 2009).

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