PID Control of Electronic Throttle for Drive by Wire Application

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Abstract

The importance of electronic throttle in modern automotive engines is obvious. The opening of the throttle blade has to be controlled. This project is an attempt to control the opening of the throttle blade to a certain position by tuning the parameters of PID controller. This is to eliminate the disturbances and make the electronic throttle perform more accurately. The purpose of this project is to develop a controlling method chosen to perform the control system analysis of electronic throttle for drive by wire applications. The results obtained shows the tuning procedures of PID controller used to control the opening of the throttle blade. It also shows the initial steps taken in order to develop an electronic throttle control system for the project as well as representing the tools needed to develop the system based on the chosen method. Thus, a general review on PID controller and its parameters as well as the H-bridge driver and the procedure analysis is required to perform controlling the opening of the electronic throttle blade using PID controller.

Keywords

H-bridge driver, closed/open loop control system, PID controller, electronic throttle motor

Introduction

Background of Study

This project investigates the performance of an electronic throttle by using PID control for drive by wire application. Electronic throttle Control (ETC) is an automobile technology that replaces the mechanical link between the accelerator pedal and the throttle. In addition, the electronic throttle is a DC motor that has many applications. This DC motor can be used in modern automotive engines to improve vehicle drivability as well as fuel economy.

In this project, the design and study of PID control will be done for an existing electronic throttle at UTP's Automotive Research Centre. First, the system will be characterized on individual components. Then a complete hardware system will be built in order to study the electronic throttle performance. The control will be implemented on a controller along on H-bridge driver and electronic throttle.

Problem Statement

As a DC motor, the electronic throttle receives a command from the controller in order to open the throttle blade to a certain position, resisting a spring force and other disturbances such as friction and stiction that can affect the electronic throttle performance.

The response of the DC motor is very fast. Current supplied to the motor needs to be controlled to enable control of the torque while turns the throttle blade to a required position.

The current to the throttle motor is controlled by an H-bridge driver using a technique called Pulse Width Modulation (PWM). Thus, the H-bridge and PWM operation needs to be investigated.

This project is an attempt to develop a control system for controlling the throttle blade by:

- Characterizing the system for Single-Input Single-Output (SISO) PID control.
- Determining a proper transfer function, block diagram and step response for the throttle operating process.
- Studying the relationship between measured voltage and % opening.
- Implementation and testing on hardware.
- Studying the effects of varying the PID parameters to obtain a stable and accurate control system.

Significance of Project

This project would help in controlling the electronic throttle for Drive by Wire applications (DbW) by using PID control so that a mechanical throttle-pedal system can be replaced by an electronic throttle system.

Objective and Scope of Study

Objectives

- The objectives of the project are:
- To study, design, and implement PID controller to operate an electronic throttle.
- To characterize the system.
- To study variations of PID parameters for controllability and stability of the system.

Scope of Study

The study begins with understanding a PID control system and characterizing a PID-controlled electronic throttle system to come up with a control block diagram. Basic input-output relationships between system components are studied and established, especially the throttle position feedback.

On the second part of the project, hardware implementation of the electronic control system will be performed. We will implement the PID control on the electronic throttle followed by testing with an H-bridge driver that is connected to the electronic throttle. Finally, controllability and stability of the system will be studied by varying and tuning the PID parameters.

Approach and Methods

Study on Bosch Electronic Throttle

As shown in Figure 1, the main purpose here is to find the relation between the torque (τ) and the angle (θ) of the throttle blade, as well as converting of the resistance and measured voltage from the voltage divider. Here, the angle (θ) represents the opening position of the throttle blade.

We have to familiarize the Pulse Width Modulation (PWM) concept in designing and functioning of the electronic throttle. PWM is based on duty cycle which is defined as the amount of time that a signal is high compared to the amount of time that the signal is low.

By observing the throttle control loop, the throttle PID controller sends a Duty Cycle signal (% PWM) to Instrumentation Driver Board (consists of H-bridge driver and voltage divider). The main purpose of the H-bridge driver is to power the throttle motor. The output of the H-bridge is current that enters the throttle motor.

Due to the injected current, there is a torque introduced in the throttle motor (actually the throttle blade)

By following Figure 1, the output of the voltage divider is a voltage that enters a software scaler in order to obtain a relation between a voltage and the angle (V vs. θ). The output of the software scaler is a throttle position (angle (θ)) that is feedback to the control system. Therefore, the importance of the angle (θ) occurs clearly in the electronic throttle in order to control the opening position of the throttle.

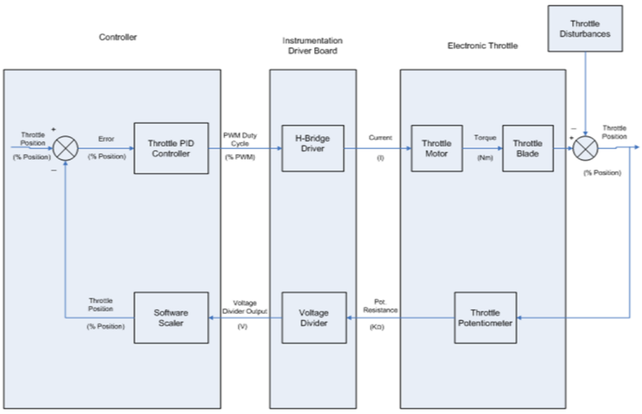

Figure 1- Electronic Throttle Control System

Characterizing the System

This involves identifying the proper PID parameters, determining the system block diagram, the transfer-function, the step response as well as the relationship of the measured voltage and the % opening of the throttle blade.

In this project, a closed-loop control system is required instead of an open- loop system. This feedback loop system will be less sensitive to disturbances compared with an open loop system [7].

According to [7], the closed loop system is very accurate in tuning procedure. The steady-state oscillation should be under process, and the PV (process variable) on a strip sharp chart should be observed as well.
Based on [1], tuning is the procedure of adjusting the feedback controller parameters to obtain a specified closed /open-loop response.
Based on [7], the following steps should be completed in order to do the closed-loop tuning procedure.

- The derivative time and the integral time (on PID) should be set to zero.
- In the automatic mode of the controller, the proportional gain *Kc* should be increased in little increments. The set-point (SP) has to have a small change in order to disturb the loop after each increment. Making these changes should be done till the oscillation is neither growing nor decaying over time.
- The proportional band (PB) should be recorded as a percent (PB = 100/*Kc*).
- The oscillation period should be recorded as well (in minutes).

The measured values should be multiplied by the factors of Ziegler- Nichols method

In the open-loop (Step Test) tuning procedures, [7] suggested that modeling any process as a first order lag and dead time as well. In this process, the PV should be noticed carefully on a strip chart as well as the output.

Tuning the open loop requires following the procedures below:

- The PID controller should be turn into a manual mode. Besides, the output should be set to a nominal value of operating. The PV should be settled completely and recorded.
- A step change should be done to the output, and its new value should be recorded as well.
- After waiting for the PV to be settled, the values derived from the chart should be determined from the output and process variable strip chart obtained.

The summarized process of tuning PID parameters using the Ziegler-Nichols Method can be noticed by following Figure below:

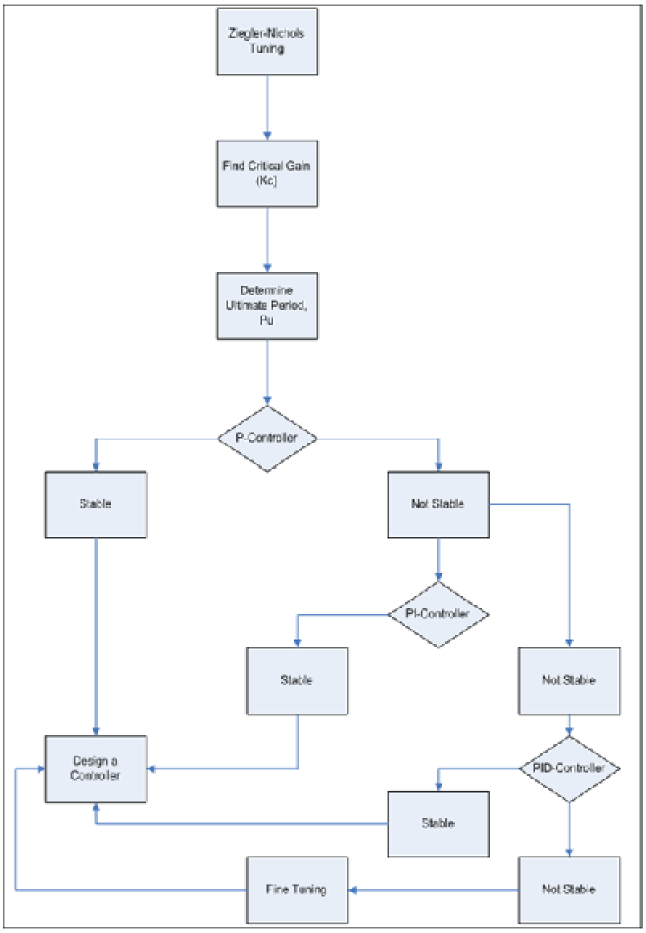

Figure 2-Flowchart of Controller Design

Implementation and Testing

At this stage, the control system will be implemented on hardware in order to achieve the experimental results. This can be conducted by implementing the control on a controller and then tested by H-bridge driver and electronic throttle.

By performing implementation on hardware located in LG lab at UTP's automotive research centre, a potential meter is used for the throttle to get more accurate output. The torque has values of 2Nm and -2 Nm as stated in Orbital datasheet because the graph available from Orbital goes from-2Nm to 2Nm. The output of this map is PWM duty cycle that enters the H-bridge driver as input. In fact, H-bridge driver is one way used to push the electronic throttle blade and power the motor of the throttle. The output of the throttle motor is voltage that enters a scaler and converts to a degree opening of the throttle blade position. Thus, the degree (Position %) is feedback to the PID controller that compares the error and does appropriate actions and calculations to accurate the control system performance.

A summary of the project procedure can be noticed by the following flowchart:

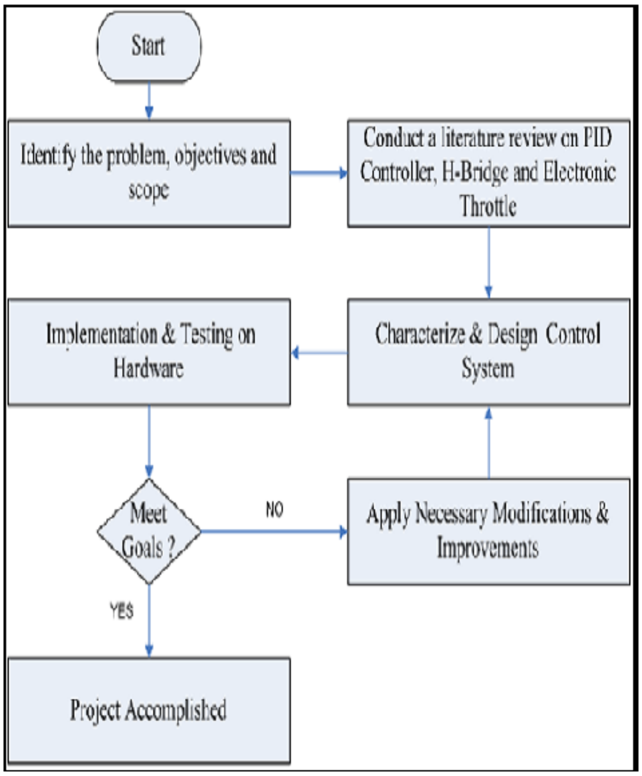

Figure 3-Overall Project Procedures

Results

Testing VNH3SP30 Fully Integrated H-Bridge Driver

In this testing, H-bridge driver is connected to a DC motor as shown in Figure 4.

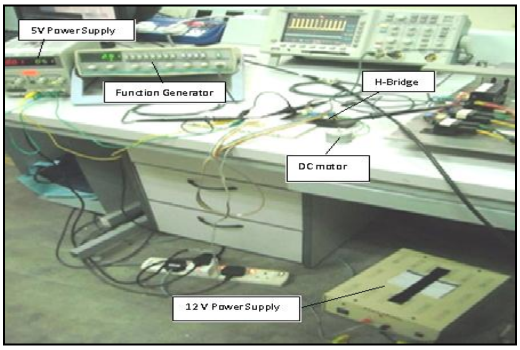

Figure 4-VNH3SP30 H-bridge Connections

Duty cycle of the PWM is varied, and the monitored mean voltage is recorded. The testing is repeated with varies PWM values of Hz such as 1 kHz, 2 kHz and 3 KHz. And the obtained graphs are as below:

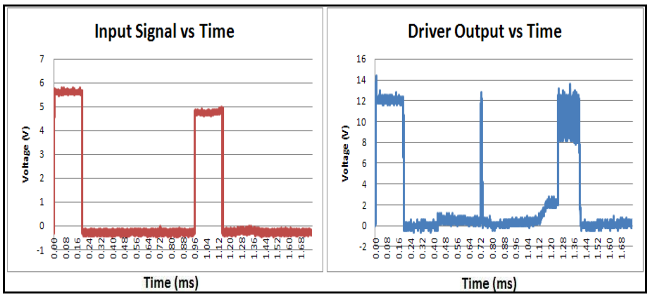

Figure 5-PWM = 20% and f = 1 kHz

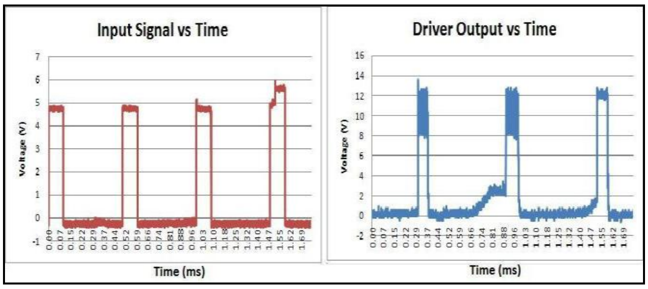

Figure 6-PWM = 20% and f = 2 kHz

Implementation and Testing of the Control System without PID controller

In this part of implementation, the control system has been tested without using the PID controller to ensure that the electronic throttle is working properly. In this testing, PWM duty cycles of 25%. 50% and 75% are sent as input to the control system in order to check the response of the electronic throttle blade's opening. The obtained result is as shown in Figure below:

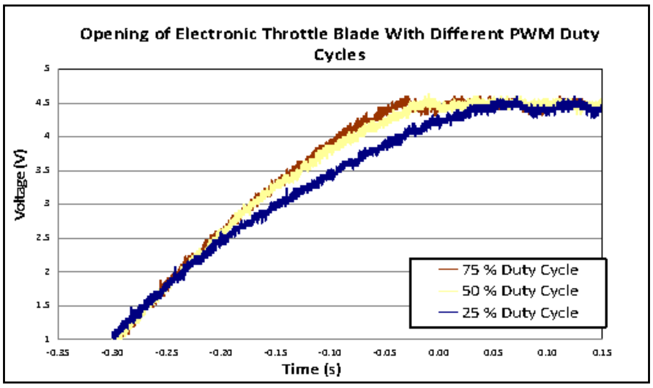

Figure 7-Opening of Electronic Throttle Blade with Different PWM Duty Cycles

Implementation and Testing Using PID controller

In this part of implementation on hardware, the PID controller is used as a main part of the control loop system. This implementation is conducted by tuning the PID parameters using Ziegler-Nichols tuning method. The software used for this implementation is Lab VIEW software as it is already installed in the computer used at UTP'S automotive research center and LG lab.

In the Lab VIEW software installed in the control system, the proportional gain, Kc is set to 0.35, the Integral time is set to 0.0152715 minutes, and the derivative time is set to 0.0038179 minutes. This is to check the response of the opening of the electronic throttle blade. After setting these values, the set-point has to change from 18 to 35 and the tuning has to quickly change from manual tuning to PID tuning. The data has to be recorded as the response of the throttle blade's opening occurs.

We have chosen various values of the proportional gain as we increase it in little increments in order to get oscillation so we can calculate the oscillation period and get accurate PID parameters for tuning process.

The obtained results for various proportional gains are as below:

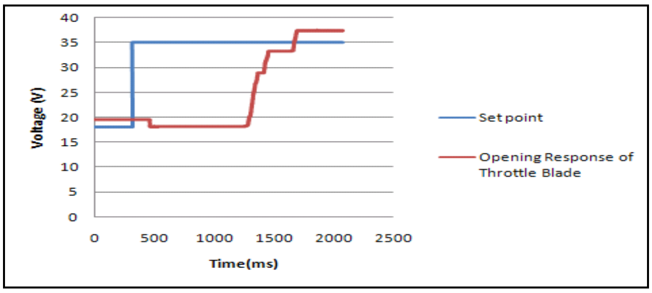

Figure 8-Opening Response of Throttle Blade when Kc = 0.35

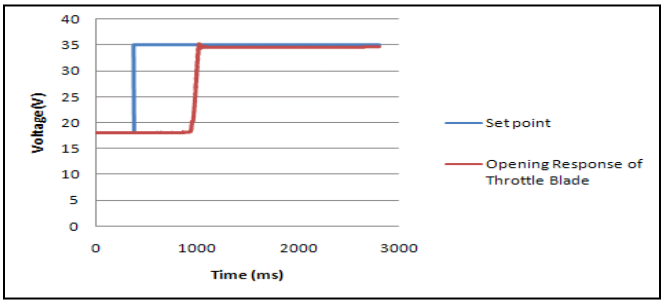

Figure 9-Opening Response of Throttle Blade when Kc = 0.55

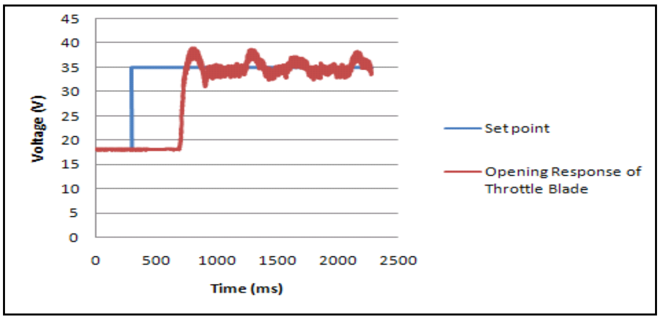

Figure 10-Opening Response of Throttle Blade when Kc = 0.65

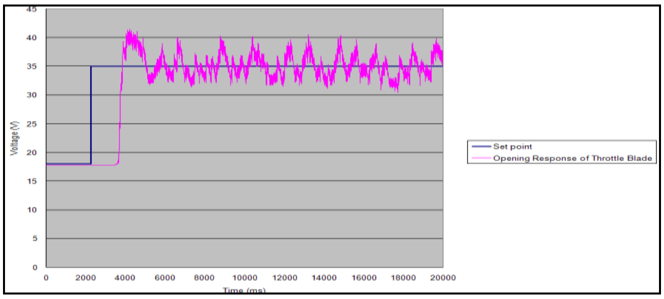

Figure 11-Opening Response of Throttle Blade when Kc = 0.75

The oscillation period (from peak to peak) equals 7000 – 5250 = 1750 ms

Discussion

Analysis of Testing VNH3SP30 Fully Integrated H-Bridge Driver

All outputs have the same square-waveform voltage corresponding to the square-waveform input signals. Besides, the as the time period gets shorter, the frequency gets higher as shown in the graphs obtained.

The duty cycle of the input signal carries over to the output waveform (same duty cycle input and output). However, each PWM duty cycle will result in different levels of average effective voltage going to the load (in this case the DC motor coil). Besides, the mean voltage (effective voltage) shown in Figure 5, with a PWM at 1 kHz will be better in use as it is close to the ideal values of the PWM and Effective Voltage.

Analysis of Testing the Control System without PID controller

As shown in Figure 7, The PWM (%) has a linear relationship with the effective voltage and the effective current as well. For instance, if the PWM has a duty cycle of 25%, the effective voltage will be 3V. If the PWM has a duty cycle of 50%, the effective voltage will be 6V and if the PWM has a duty cycle of 100%, the effective voltage will be 12V.

From the obtained results, as Duty Cycle increases, the Effective voltage increases as well. More effective voltage means more current flow means more torque applied, thus, as the torque increases, the speed response of the Electronic Throttle Blade increases.

Analysis of Implementation and Testing Using PID controller

As shown in Figure 8, when proportional gain = 0.35, the response time taken for the throttle blade to be opened is 10.25 s. this means that the performance of the opening of the throttle blade is not acceptable. When the proportional gain = 0.55, the time taken is 7.98s and the obtained graph (Figure 9) shows that the performance is more stable as compared to Figure 8.

Besides, the opening response of throttle blade when Kc = 0.65, is started to oscillate (unstable). For the graph obtained in Figure 11, the value of the proportional gain = 0.75 is chosen for Ziegler-Nichols method in order to calculate the values of P, PI and PID.

From Figure 11, the oscillation time = 1750 ms. This time is used to fill the Ziegler-Nichols closed loop tuning correlations. In addition, the sampling rate equals: 1 second / 200 samples as used =0.005s = 0.005 * 1000 = 5 ms. Thus, every 2 samples, the PID controller makes one decision.

Conclusion

As a conclusion, the use of electronic throttle can be clearly noticed in modern automotive engines. Therefore, electronic throttle for drive by wire applications needs a very good control strategy. Obviously, beside the voltage and the potentiometer resistance, the angle (θ) and torque (τ) play a very important role in controlling the opening of the throttle blade into a certain position.

This project investigates the performance of the electronic throttle blade by using PID controller, H-bridge driver and Lab-VIEW software. The PID controller is used to correct the error between a measured process variable and a desired set point in order to make an accurate decisions and actions to control the system. The H-bridge driver is used to power the throttle motor and ease the opening process of the throttle blade. The well functioned H-bridge driver, the more accurate values can be obtained in this project.

The relation between the pulse with modulation (PWM) and the effective voltage and current is linear. Thus, more duty cycle means more effective voltage. More effective voltage means more current flow means more torque applied, thus, as the torque increases, the speed response of the electronic throttle blade increases.

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References

[1] Thomas E. Marlin. (2000). Process Control Designing Process and Control System for Dynamic Performance, 2nd Edition, McGraw Hill.

[2] Andreas Pechlaner, Hermann Kern and Frank Auer, "Electronic Throttle Control", System Engineering Automotive Application Note, Pages 9-12.

[3] Norman S. Nise. (2004). Control System Engineering, United States: Wiley International Edition.

[4] Curtis D. Johnson, Process Control Instrumentation Technology, 8th edition, chapter 9.

[5] Chuck McManis. (23rd Dec 2006). "H-Bridges: Theory and Practice", retrieved from http://www.mcmanis.com/chuck/robotics/tutorial/h-bridge/

[6] Cyril BUTTAY. (9 Jun, 2006). "H-Bridge". Retrieved from http://en.wikipedia.org/wiki/H-bridge

[7] National Instrument, LabVIEWPID Control Toolset User Manual, 2002, chapters 2 and 3.

[8] The MATHWORKS, Inc., Control System Toolbox User's Guide-for Use with MATLAB, Version 4, 1998.

[9] Araki M. (2003). Control Systems, Robotics and Automation: PID Control, Volume II.

[10] X.Yuan and Y. Wang, 2008, "Neural Networks Based on Self-Learning PID of Electronic Throttle," CHP 55: 385-393.

[11] Fully Integrated H-bridge Motor Driver User Manual, retrieved from http://www.pololu.com/catalog/product/705

[12] PID controller Retrieved from http://en.wikipedia.org/wiki/PID_control