ADAPTIVE CONTROL TECHNIQUE FOR ELECTRONIC THROTTLE CONTROL ACTUATOR

A PROJECT REPORT

Submitted by

HASEEBUR RAHMAN H

(15MTR031)

IRSHATH AHAMED A

(15MTR034)

MOULY PRASAANTH L A

(15MTR058)

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(Autonomous)

PERUNDURAI ERODE - 638060

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DEPARTMENT OF MECAHTRONICS ENGINEERING

KONGU ENGINEERING COLLEGE

(Autonomous)

PERUNDURAI   ERODE – 638060

APRIL 2019

BONAFIDE CERTIFICATE

This is to certify that the Project report entitled **ADAPTIVE CONTROL TECHNIQUE FOR ELECTRONIC THROTTLE CONTROL ACTUATOR** is the bonafide record of project work done by **H.HASEEBUR RAHMAN (15MTR031)**, **A.IRSHATH AHAMED (15MTR034) and L.A.MOULY PRASAANTH (15MTR058)** in partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechatronics Engineering of Anna university Chennai during the year 2018 - 2019.

SUPERVISOR **HEAD OF THE DEPARTMENT**

Date:

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

DEPARTMENT OF MECAHTRONICS ENGINEERING

KONGU ENGINEERING COLLEGE

(Autonomous)

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APRIL 2019

DECLARATION

We affirm that the Project Report titled **ADAPTIVE CONTROL TECHNIQUE FOR ELECTRONIC THROTTLE CONTROL ACTUATOR** being submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering is the original work carried out by us. It has not formed the part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

Date

HASEEBUR RAHMAN
(15MTR031)

A.IRSHATH AHAMED
(15MTR034)

L.A.MOULY PRASAANTH
(15MTR058)

I certify that the declaration made by the above candidates is true to the best of my knowledge.

Date:

SUPERVISOR

ABSTRACT

Electronic throttle control system is widely adapted in the Automotive application for better drivability, fuel economy and reduces the emissions. Electronic throttle control facilitates the integration of features such as cruise control, traction control and stability control. In such systems, pedal follower based approach are used for calculating the required throttle angle for the given torque demand by the driver. Electronic throttle body has some nonlinearities due to friction and limp home spring. This project presents a throttle control system for the given accelerator position by reducing such non linearities in Electronic throttle body. A mathematical model for an electronic throttle body is developed to understand the effects of nonlinearities due to friction and limp home dual springs. A PID controller with compensators are developed to handle the nonlinearities to get better electronic throttle control system. A simulation study has been carried out using software in loop for step and sinusoidal input signals. The responses of electronic throttle body for opening the throttle angle and error are analyzed for the given input signals. The simulation result shows that the proposed PID controller with compensators has significant advantage in reducing the throttle angle error and gives the desired output.

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LIST OF ABBREVIATIONS

S. N0	ABBREVIATION	SYMBOL
01	Electronic Throttle Body	ETB
02	Limp Home	LH
03	Linear Parameter Varying	LPV
04	Electronic Throttle Control	ETC
05	Engine Management System	EMS
06	Model Reference Adaptive Control	MRAC
07	Throttle Position Sensor	TPS
08	Minimal Control Synthetics	MCS
09	Software in Loop	SIL
10	Proportional integral derivative	PID
11	Accelerator position sensor	APS

CHAPTER 1

INTRODUCTION

1.1 Throttle Body

In fuel injected engines, the throttle body is the part of the air intake system that controls the amount of air flowing into the engine, in response to driver accelerator pedal input in the main. The throttle body is usually located between the air filter box and the intake manifold, and it is usually attached to, or near, the mass airflow sensor. The largest piece inside the throttle body is the throttle plate, which is a butterfly valve that regulates the airflow.

On many cars, the accelerator pedal motion is communicated via the throttle cable, which is mechanically connected to the throttle linkages, which, in turn, rotate the throttle plate. The throttle valve which opens and closes to adjust the air-flow into the engine is controlled by a cable connecting the accelerator pedal. The actual image of mechanical throttle body as shown in Figure 1.1.

Figure 1.1. Mechanical throttle body

1.2 Electronic Throttle Body

Electronic throttle body is widely preferred to control the air intake for regulating the engine torque in order to meet the performance and emission requirements of automobile. This system is gradually increasing in the modern automobiles in order to provide a multiple technical benefits such as better vehicle response, high performance in terms of improving the fuel economy and trim down the emissions. A typical electronic throttle body (ETB) is a device which consists of a butterfly valve operated by a DC servo motor through a set of gear arrangements, a dual return spring in order to place the valve in LH (Limp Home) position, a redundant position sensor to measure the actual angle of throttle valve for the feedback. The throttle cable has been replaced by the accelerator position sensor (APS), which detects the exact position of the pedal at any given moment, transmitting this signal to the ETC module. The ETC module reads input from the APS and transmits servomotor instructions to the throttle body. Basically, when the driver depresses the accelerator 25%, the ETC opens the ETB to 25%, and when the driver releases the accelerator, ETC closes the ETB. Based on the driver requirements, the throttle angle has to be precisely maintained in order to obtain the better throttle response and drivability. However, the presence of nonlinearities in the system, such as friction and limp-home position affects the position accuracy of the throttle valve. Figure 1.2 shows the schematic view of electronic throttle body.

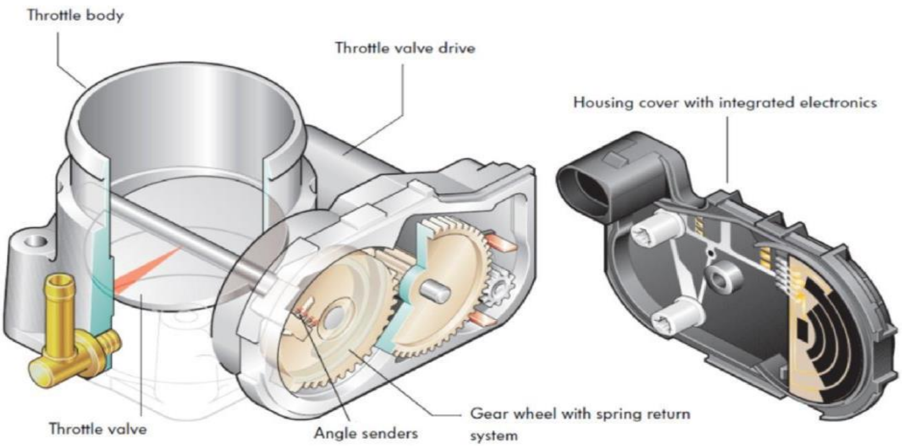

Figure 1.2. Schematic view of electronic throttle body

The throttle valve control in automotive should be more responsive and more robust to handle the various disturbances in the system. This work features the design of position control system for the throttle valve based on the driver's torque demand for a 305cc SI engine using a Bosch ETB shown in Figure.1.3.

Figure 1.3. Electronic throttle body

This work focus on the design of the control system for throttle angle estimation based on the drivers torque demand and positioning the throttle valve by considering the nonlinearities such as friction and limp home return spring in the electronic throttle body for automotive engine is developed. Figure 1.4 shows the Pedal follower-based throttle control system.

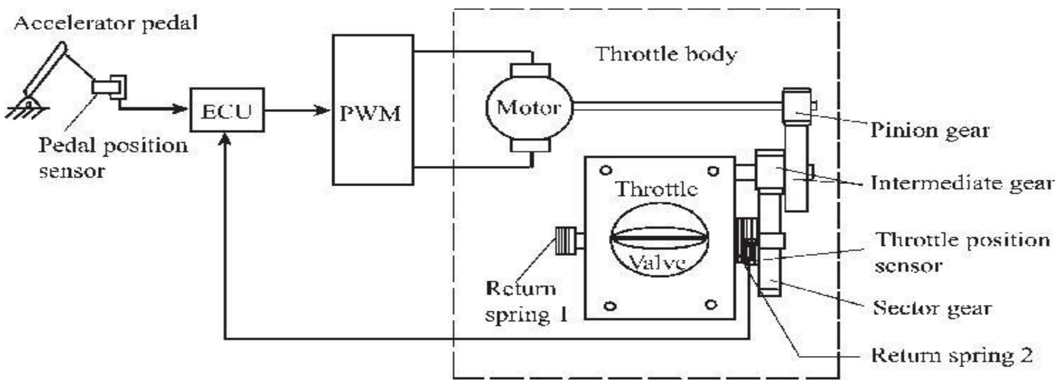

Figure 1.4. Schematic view of electronic throttle control system (Pedal follower)

1.3 Overview of the Project

Chapter 1: Introduce the electronic throttle body and electronic throttle control system.

Chapter 2: Contains various literature reviews involved in electronic throttle control design and analysis.

Chapter 3: Describes the objective and proposed technique used to analyze electronic throttle control.

Chapter 4: Deals with the design of electronic throttle body and its components.

Chapter 5: Contains details about the throttle angle estimation used for electronic throttle control

Chapter 6: Simulation and Experimental analysis of electronic throttle control system is discussed for different conditions.

Chapter 7: Summarize the major conclusions of the project and suggestions for the future scope.

CHAPTER 2

LITERATURE REVIEW

Wang et al (2018) proposed a practical tracking control scheme of an AET system developed using a continuous fast non-singular terminal sliding mode (CFNTSM) technique based on uncertainty observer. By using the prescribed CFNTSM surface and fast terminal sliding mode-based reaching element, the proposed control implementation guarantees the fast error convergence characteristic and high tracking accuracy under parameter uncertainties and perturbations. Furthermore, due to the adoption of the finite-time exact observer (FEO) for the lumped uncertainty estimation in the controller, the ease of the selection of the control gains is well achieved since they only depend on the uncertainty estimation error. The closed-loop stability and finite-time convergence are presented based on the Lyapunov stability theory. Experimental verifications are conducted to validate the remarkable performance of the proposed control, in terms of the step and sinusoidal tracking as well as anti-disturbance ability.

Bai (2018) proposed an adaptive sliding-mode tracking control strategy for an ET. Compared with the existing control strategies for an ET, input saturation constraints and parameter uncertainties are adequately considered in the proposed control strategy. At first, the nonlinear dynamic model for control of an ET is described. According to the dynamical model, the nonlinear adaptive sliding-mode tracking control method is presented, where parameter adaptive laws and auxiliary design system are employed. Parameter adaptive law is given to estimate the unknown parameter with an ET. An auxiliary system is designed, and its state is utilized in the tracking control method to handle the input saturation. Stability proof and analysis of the adaptive sliding-mode control method is performed by using Lyapunov stability theory. Finally, the reliability and feasibility of the proposed control strategy are evaluated by computer simulation. Simulation research shows that the proposed sliding-mode control strategy can provide good control performance for an ET.

Jiao et al (2014) proposed an adaptive servo control strategy is presented for the electronic throttle control system. Compared with the existing results on the electronic throttle control schemes, in this paper, the throttle valve reference tracking controller comprises a proportional-integral-derivative-type feedback controller with adaptive gain parameters, an adaptive feed forward compensator, and adaptive nonlinearity compensators for friction, limp-home (LH), and backlash. The closed-loop controller is realized by only utilizing the information of the throttle valve position measured by a cheap potentiometer of low resolution. The theoretical proof and analysis show that the designed throttle control system can ensure fast and accurate reference tracking of the valve plate angle in the case of the uncertain parameters related to production deviations, variations of external conditions and aging, and the effects of transmission friction, return-spring LH, and gear backlash nonlinearity with uncertain parameters. Moreover, the capability of the adaptive controller to preserve the transient performance and accuracy is evaluated in both simulation and experiment.

Eskil and Yildirim (2017) proposed the study of various control approaches to control the speed of a heavy-duty vehicle using an electronic throttle control system. However, the DC servo motor is used for controlling the angular position of electronic throttle valve. Moreover, four control techniques are used to control prescribed two different random inputs of the heavy duty vehicle speed. These control structures are named as standard PID controller, model-based neural network controller, adaptive neural network-based fuzzy inference controller and proposed robust adaptive neural-based fuzzy inference control systems. On the other hand, the time performance specifications such as rise time, settling time, peak time, and peak value and steady-state error are also examined for these control approaches. The results of the simulation for four approaches showed that the proposed robust adaptive neural network-based fuzzy inference control system has better performance rather than other standard control systems under varying speed conditions. Finally, the proposed control system structure will be implemented for speed control of DC servo motor.

Jiao et al (2018) an adaptive finite time servo control (AFTSC) strategy by integrating adaptive back stepping recursive technique into the framework of finite-time stability theory. The required transient performance of the throttle opening trajectory tracking is guaranteed theoretically by the finite convergence time and the convergence rate related to the adjustable control parameters. The static performance is enhanced by introducing the tracking error integral into the system state variables. The robustness of the satisfactory transient and static performance is improved by the adaptive update law in the light of system parameter uncertainties due to production deviations, different working conditions and aging. Meanwhile, the advantage of the proposed AFTSC strategy is validated by demonstrating the comparison results with the existing strategies both in the critical operating cases under MATLAB/Simulink simulation environment and in the actual operating cases on the SPACE rapid-control-prototype (RCP) test platform for a real electronic throttle system

Vargas et al (2016) proposed an application of unscented Kalman filters (UKFs) to an automotive electronic throttle device. The motivation of this study is on estimating the position of the throttle device when measurements of the position are inaccessible, e.g., due to failures in the sensor of position. In this case, an external wattmeter is connected in the circuitry to measure the power consumed by the throttle, and this information feeds UKFs to produce the estimation for the position. Experimental data support the findings of this paper. Almost all of the brand-new vehicles based on spark-ignition combustion engines have an electronic throttle valve to control the power produced by the engine. The electronic throttle has a unique sensor for measuring the position of the throttle valve, and this feature can represent a serious problem when the sensor of position fails. As an attempt to prevent the effects of a failure from such a sensor, they present an algorithm (UKF) combined with the use of an additional sensor, i.e., a wattmeter. The wattmeter is detached from the throttle’s structure but is arranged to measure the electric power consumed by the throttle. Measurements of the power consumption then feed the UKF. This filter then produces an estimation of the position of the throttle valve. Experimental data illustrate the practical benefits of the approach.

Li et al (2015) an extended-state-observer-based double-loop integral sliding-mode controller for electronic throttle (ET) is proposed by factoring the gear backlash torque and external disturbance to circumvent the parametric uncertainties and nonlinearities. The extended state observer is designed based on a linear model of ET to estimate the change of throttle opening angle and total disturbance. A double-loop integral sliding-mode controller consisting of an inner loop and an outer loop is presented based on the opening angle and opening angle change errors of ET through Lyapunov stability theory.

Numerical experiments are conducted using simulation. The results show that the accuracy and the response time of the proposed controller are better than those of the back-stepping and sliding mode control.

Podivilova et al (2016) polyhedral approximation algorithm for set-valued estimation of switching linear systems. The algorithm generates set-valued estimates for any possible sequence of switching parameters, under the assumption that the system has unknown but bounded disturbances and measurement noises. This algorithm has practical implications; namely, set-valued estimates were generated for the position and electrical current of a real-time automotive electronic throttle valve, and the corresponding experimental data demonstrate the practical benefits of the approach.

Sun et al (2018) proposed a fuzzy approach for optimal robust control design of automotive electronic throttle (ET) system. Compared with the conventional ET control systems, they establish the fuzzy dynamical model of the electronic throttle system with parameter uncertainties, nonlinearities, and external disturbances which may be nonlinear, (possibly fast) time-varying. These uncertainties are assumed to be bounded, and the knowledge of the bound only lies within a prescribed fuzzy set. A robust control which is deterministic and is not the usual if then rules based control is presented to guarantee the controlled system to achieve the deterministic performance: uniform boundedness and uniform ultimate boundedness. Furthermore, a fuzzy-based system performance index including average fuzzy system performance and control cost is proposed based on the fuzzy information. The optimal design problem associated with the control can then be solved by minimizing the fuzzy-based performance index. With this optimal robust control, the performance of the fuzzy electronic throttle system is both deterministically guaranteed and fuzzily optimized.

Wang et al (2016) proposed a robust adaptive position control scheme for automotive electronic throttle (ET) valve. Compared with the conventional throttle control systems, in this paper, a robust adaptive sliding mode (RASM) control scheme is developed in order to eliminate the effects of the parameter uncertainties and nonlinearities including friction, return-spring limp-home and gear backlash. It is shown that both the lumped uncertainty bound and the control gains are adaptively estimated by the update laws, such that not only the bound information of the lumped uncertainty and the control gains are no longer required, but also a robust tracking performance can be ensured in the presence of the parametric variations and disturbances. The comparative simulation and experimental studies are demonstrated to verify the excellent transient and steady-state tracking performance of the proposed RASM controller for ET systems.

Ali et al (2014) proposed CDM technique has been designed to enhance the performance and robustness against system uncertainties. Simulation studies confirm the superior robustness and frequency control effect of the proposed HP and EV controllers in comparison to other conventional controllers of HPs and EVs like the conventional PID controllers optimized using practical swarm controllers based a specified-structure. This paper applies the Coefficient Diagram Method (CDM) as a new robust controller design of heat pump (HP) and plug-in hybrid electric vehicle (EV) for frequency control in an isolated small power system powered by diesel generator and renewable photovoltaic PV power source. In order to reduce frequency fluctuation resulted from the fluctuating power generation from renewable energy sources, the smart control of power consumption of HP and the power discharging of EV in the customer side can be performed

Baykara et al (2017) proposed, a novel alternative engine valve control technique to perform a cycle without gas exchange (skip cycle), is examined. The goal of skip cycle strategy is to reduce the effective stroke volume of an engine under part load conditions by skipping several of the four stroke cycles by cutting off the fuel injection and simultaneously deactivating the inlet and exhaust valves. To achieve the same power level in the skip cycle, the cylinder pressure level reaches higher values compared to those in a normal four stroke cycle operation, but inherently not higher than the maximum one at full load of normal cycle. According to the experimental results, the break specific fuel consumption (BSFC) was reduced by 14–26% at a 1–3 bar break mean effective pressure (BMEP) and a 1200–1800 rpm engine speed of skip cycle operation, in comparison to normal engine operation. The significant decrease in the pumping work from the gas exchange is one of the primary factors for an increase in efficiency under part load conditions. As expected, the fuel consumption reduction rate at lower load conditions was higher. These experimental results indicate a promising potential of the skip cycle system for reducing the fuel consumption under part load conditions.

Ashok et al (2016) proposed an engine management system (EMS) is a mixed-signal embedded system interacting with the engine through number of sensors and actuators. In addition, it includes an engine control algorithm in the control unit. The control strategies in EMS are intended for air-to-fuel ratio control, ignition control, electronic throttle control, idle speed control, etc. Hence, the control system architecture of an EMS consists of many sub-control modules in its structural design to provide an effective output from the engine. Superior output from the engine is attained by the effective design and implementation of the control system in EMS. The design of an engine control system is a very challenging task because of the complexity of the functions involved. This paper consolidates an overview of the vital developments within the SI engine control system strategies and reviews about some of the basic control modules in the engine management system.

2.1 Summary of literature

Electronic throttle control (ETC) system has turned into an extremely prominent system with a specific end goal to vary the intake airflow rate to provide a better fuel economy, emissions, drivability and for integration with other systems in spark ignition engines. However, existence of nonlinearities in the system, such as limp-home position, friction and aging affects leads to the position accuracy of the throttle valve. Two approaches are followed in the throttle angle estimation of ETC, such as the pedal follower and torque-based methods. The pedal follower method is proposed for the angle estimation by measuring the accelerator position using sensor. A control system strategy is required to handle such non-linearities in the system for throttle valve opening and the position control. A simple adaptive PID controller is used with nonlinearities compensation in a closed loop structure to achieve better response of a system.

CHAPTER 3

PROBLEM DESCRIPTION

3.1 OBJECTIVE

To develop an adaptive PID controller with frictional and limp home spring compensator to remove nonlinearities present in electronic throttle control system and to analyse the performance in MATLAB / Simulink platform.

3.2 EXISTING TECHNIQUE

Model reference adaptive control (MRAC) methods based on the minimal control synthetics (MCS) have been proposed for generic Linear time – invariant systems affected by non-linear disturbances and for control of switched systems and piecewise affine systems (Montanaro et al., 2014). These strategies have the advantages of not requiring a precise knowledge of the plant model or its parameters. Furthermore, their adaptive mechanisms for updating the control parameters are simple, hence they are particularly suitable for implementation in commercial ECUs. Even though MCS algorithms have shown to the robust with respect to the ETB nonlinearities, performance required by the automotive industry is not fulfilled in some operation conditions, especially around the limp-home region.

3.3 PROPOSED TECHNIQUE

A throttle control system is proposed for the precise estimation of throttle angle based on the pedal follower for the given accelerator position measured by sensor. A mathematical model for electronic throttle body is developed to understand the effects of nonlinearities due to friction and limp home dual springs. A PID controller with compensators are developed to handle the nonlinearities due to friction and limp home dual springs in the proposed electronic throttle control system. A simulation study has been carried out using software in loop simulation approaches for step and sinusoidal input signals. The responses of electronic throttle body for opening the throttle angle and error are analyzed for the given input signals.

CHAPTER 4

DESIGN OF ELECTRONIC THROTTLE BODY

Precise positioning of the throttle valve is important for regulating the airflow and torque requirements of the engine. However, there is variation in the actual position of the throttle valve as compared to desired throttle angle input due to the nonlinearities such as friction and limp home position in the system. To avoid the nonlinear effects on the angular positioning of throttle valve, a virtual model has been developed and it is explained in the subsequent sections. Typical electronic throttle body shown in Figure 4.1 consisting of DC servo motor, gearbox and dual return spring. For the desired throttle angle input, the throttle control system provides a motor voltage (U_{Motor}) signal to the H-Bridge driver circuit. For actuating the motor, H-bridge creates a motor armature current with an equivalent direction and duty cycle. To reduce the position error of the throttle valve a closed loop feedback control system is accomplished by using a throttle position sensor signal.

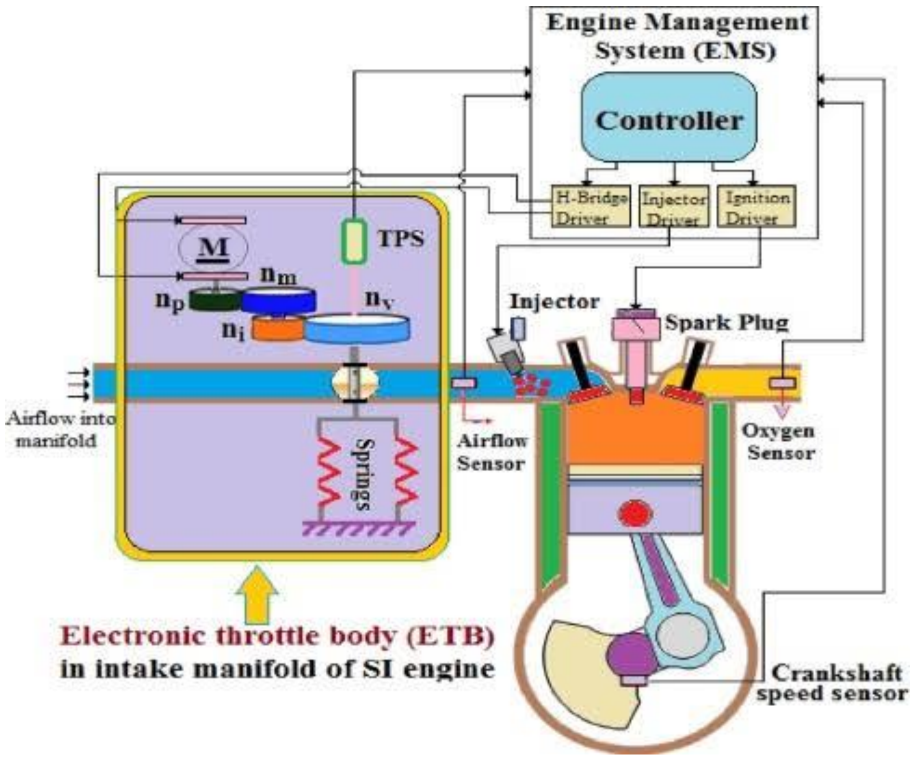

Figure 4.1. Schematic of electronic throttle body system components.

4.1 Modeling of DC Motor

The most common device used as an actuator in mechanical control is the DC motor. The precise positioning of the throttle valve angle is changed by using the DC motor and it consists of permanent magnet, armature coil, armature resistance R_a and winding leakage L shows in Figure 4.2.

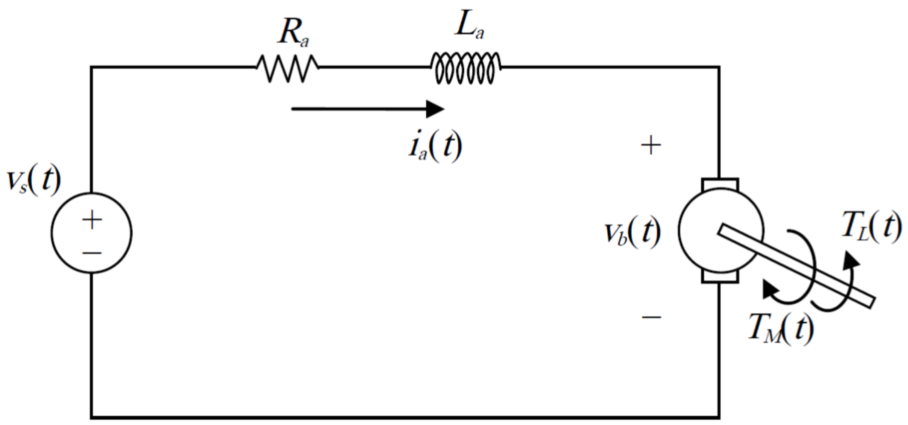

Figure 4.2. Schematic of DC Motor

By applying, kirchoff's voltage law to the circuit the electrical equation of DC motor is described as

$$\boldsymbol{v_s(t) = R_a\, i_a(t) + L_a \frac{di_a(t)}{dt} + v_b(t)} \tag{4.1}$$

Where, i_a is the armature current, $v_b(t)$ is back emf voltage and $v_s(t)$ is the voltage source. The back emf voltage $v_b(t)$ is proportional to the angular velocity ω(t) of the rotor in the motor, expressed as

$$\boldsymbol{v_b(t) = k_b \omega(t)} \tag{4.2}$$

Where k_b is the back emf constant. In addition, the motor generates a torque T_m Proportional to the armature current, given as

$$\boldsymbol{T_m = k_t i_a(t)} \tag{4.3}$$

where k_t is the torque constant.

From equation (4.1) and (4.2) the SIMULINK model of DC motor as shown in Figure 4.3 was developed virtually for analyzing the throttle body motor dynamics.

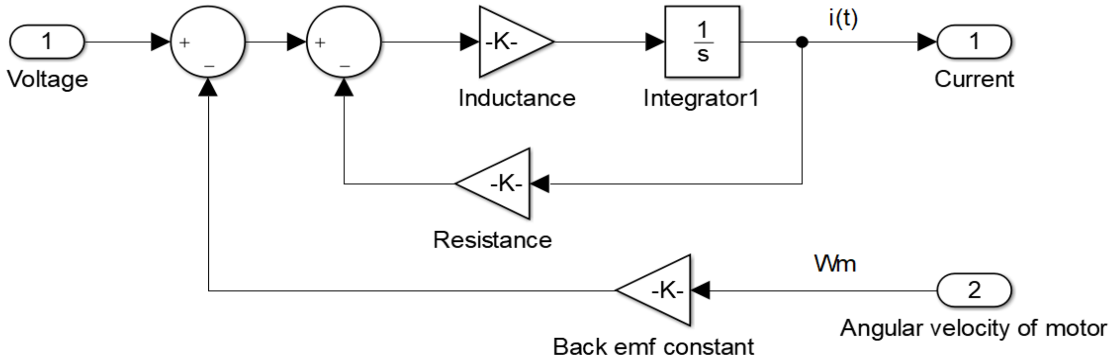

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Figure 4.3. SIMULINK Model of DC Motor

4.2 Gear arrangements

Gear is a mechanical component which is used to transmit torque from one place to another place. The torque from DC motor shaft has not enough to open the valve with spring return mechanism. So that motor torque is amplified through the Gear trains. The butterfly valve is linked to the motor by means of the gear arrangements as shown in Figure 4.4. The gear set consist of pinion gear(n_p), motor gear(n_m), an intermediate gear(n_i) and valve gear(n_v).

Figure 4.4. Gear box of Throttle body

The equation for the gear ratio (G_r) between the motor shaft and throttle plate is given as in Equation (4.4),

$$\boldsymbol{G_r} = \frac{n_v}{n_i} \times \frac{n_m}{n_p} \tag{4.4}$$

4.3 Limp Home Position Spring Model

Electronic throttle body has two inbuilt springs to keep the throttle valve open at a default position in the event of malfunction in the electronic throttle or other systems. Each spring is acting independently on its respective direction, and both are pre-compressed. The throttle body used for this work has the spring balance point or the limp home position which varies between 14.5° (θ^- Limp-home) and 15.5° (θ^+ Limp-home) as shown in Figure 4.5. This variation in limp positive and negative is due to the construction flaws in the throttle body, aging, etc. Their mean position is assumed as limp-home position (i.e. 15°). The mean position of the throttle plate was called as limp home region which is the fail safe location. The positions of limp home, maximum and minimum angle for the throttle body are varied for the different category of engine throttle bodies according to the requirements.

The spring torque is a piecewise linear function but the spring constant differs greatly, and spring torque depends on whether throttle valve is in the limp home, forward or reverse position as shown in Figure 4.5.

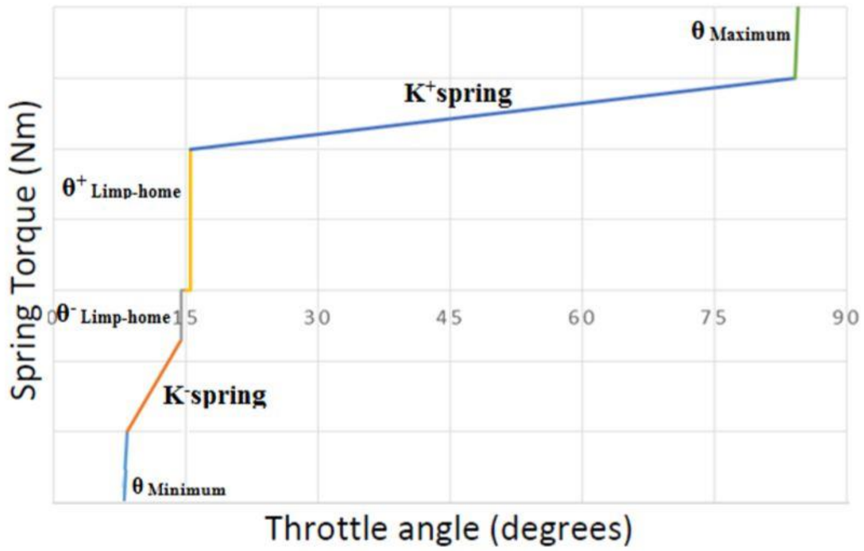

Figure 4.5. Variation of spring torque with throttle angle

$$\boldsymbol{T^{+}}_{\boldsymbol{spring}} = \boldsymbol{K^{+}}_{\boldsymbol{spring}} \times (\boldsymbol{\theta}_{\boldsymbol{spring}}) \tag{4.5}$$

Where,

$$\boldsymbol{\theta}_{\boldsymbol{spring}} = (\boldsymbol{\theta}_{\boldsymbol{throttle}} - \boldsymbol{\theta^{+}}_{\boldsymbol{limp}} + \boldsymbol{\theta^{+}}_{\boldsymbol{pre-load}}) \tag{4.6}$$

The analytical function of the restoring spring torque feature is given as four pieces of function and is expressed as in piecewise linear function which is derived from Eq. (4.5) and (4.6) for the nonlinearity compensation of spring torque in Electronic throttle body.

$$T_{spring} = \begin{cases} T^{-}_{pre-load} - K^{-}_{spring}(\theta_{throttle} - \theta^{-}_{Limp}) & if\ \theta_{throttle} < \theta^{-}_{Limp} \\ 2*T^{-}_{pre-load}(\theta_{Limp} - \theta_{throttle}) & if\ \theta_{Limp} < \theta_{throttle} \leq \theta^{-}_{Limp} \\ 2*T^{+}_{pre-load}(\theta_{throttle} - \theta_{Limp}) & if\ \theta_{Limp} < \theta_{throttle} \leq \theta^{+}_{Limp} \\ T^{+}_{pre-load} + K^{+}_{spring}(\theta_{throttle} - \theta^{+}_{Limp}) & if\ \theta^{+}_{Limp} < \theta^{+}_{throttle} \end{cases} \quad (4.7)$$

From Eq. (4.6) Torque produced by spring for each cases of function is developed in Simulink model as shown in Figure 4.6 for compensation of nonlinearities.

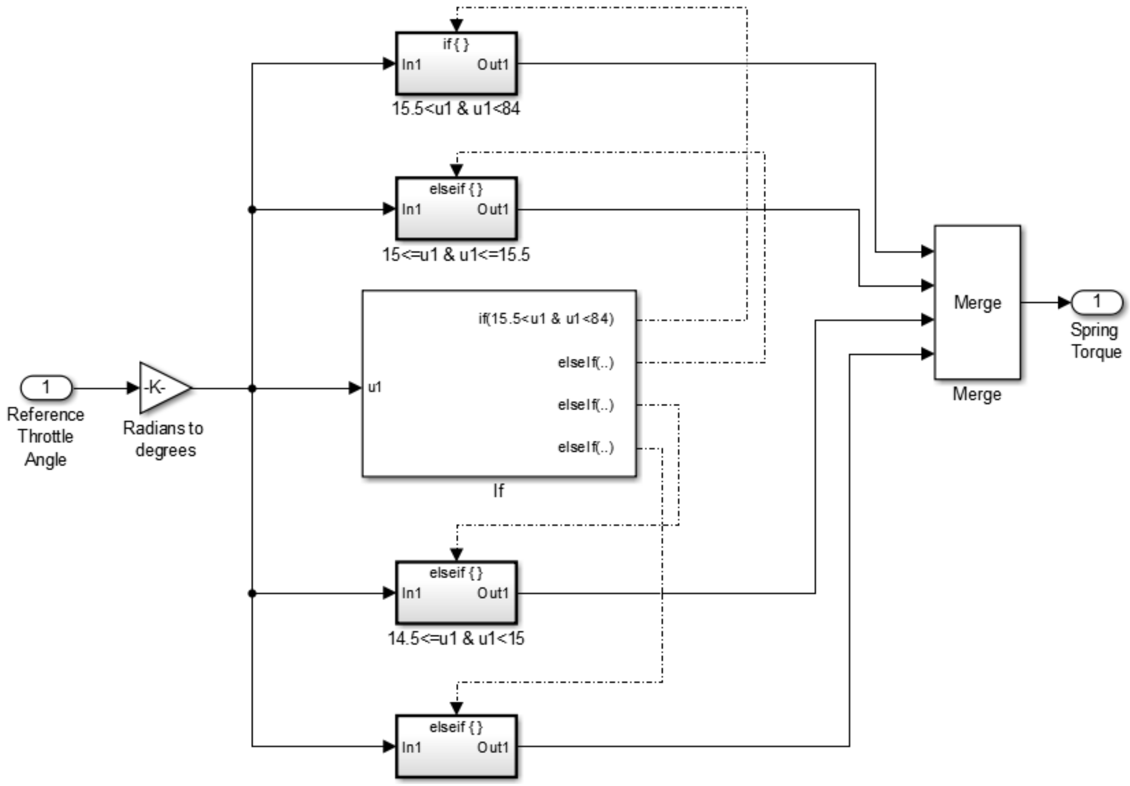

Figure 4.6. Limp home spring compensator

4.4 Friction Model

As the throttle valve moved by the servo motor, it has to overcome frictional forces created by the gearbox and as well as in the throttle valve which act as a nonlinear phenomenon in the system. The frictional forces create a frictional torque (T_{static} friction) which opposes the direction of the motion. For the modeling of throttle body system, dry (Coulomb) friction and viscous friction are considered. A signum function is used to assess the direction of frictional torque depending on the direction of angular velocity. The signum function is

$$sign(x) = [-1 \text{ for } x<1, 0 \text{ for } x=0, +1 \text{ for } x>1] \tag{4.8}$$

As there are two different springs are acting in their respective active region, direction of friction is dependent on the direction of motion. Thus, the frictional torque acting upon the system is related to the throttle movement direction (i.e. sign of velocity of throttle plate movement) as shown in Figure 4.7 referred from (Ashok et al.,2017). This condition is included by using signum function and the static frictional torque is modeled using coulomb friction which is represented as in Eq. (4.9),

$$\mathbf{T_{static} = T_{coulomb} * sign(W_{throttle})} \tag{4.9}$$

Another friction factor is the viscous friction and is directly proportional to the throttle angular velocity. Its direction is always opposite to movement. Hence torque due to viscous friction is given as in Eq. (4.10),

$$T_{viscous} = -C_{coulomb} * \frac{d\theta_{throttle}}{dt} \tag{4.10}$$

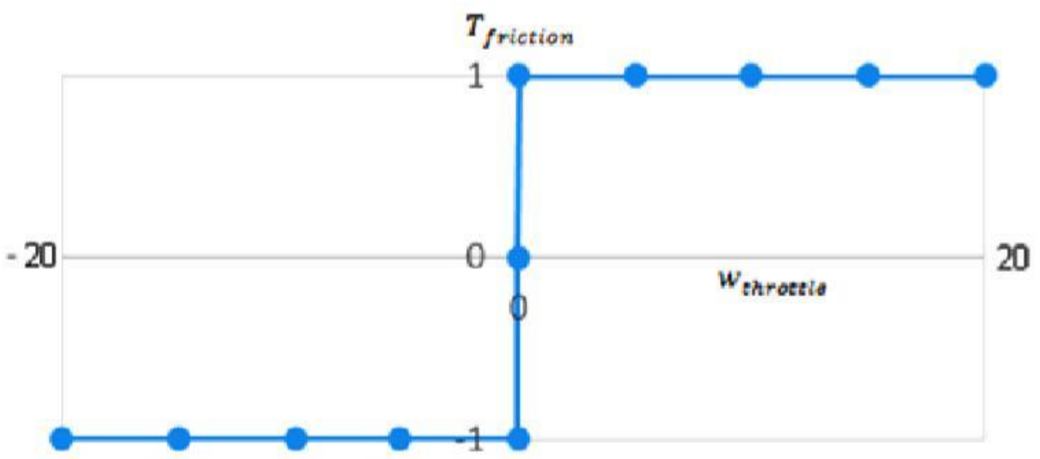

Figure 4.7. Variation of frictional torque with throttle angular velocity

CHAPTER 5

ELECTRONIC THROTTLE CONTROL SYSTEM

The proposed electronic throttle control system of automotive engine has electronic throttle control module as shown in Figure 5.1. In the proposed approach, torque demand by the driver is estimated for the given accelerator position, When the accelerator pedal is pressed down by the driver, The ETC module reads input from the accelerator position sensor and transmits this signal to electronic throttle control module and then sent to the MCU in Engine Management System for the purpose of determining the appropriate air-fuel mixture to be fed into the engine said by (wang et al, 2016). further, the required throttle for the given torque demand is calculated and provided to the control system. The following section gives the description of this control modules in detail.

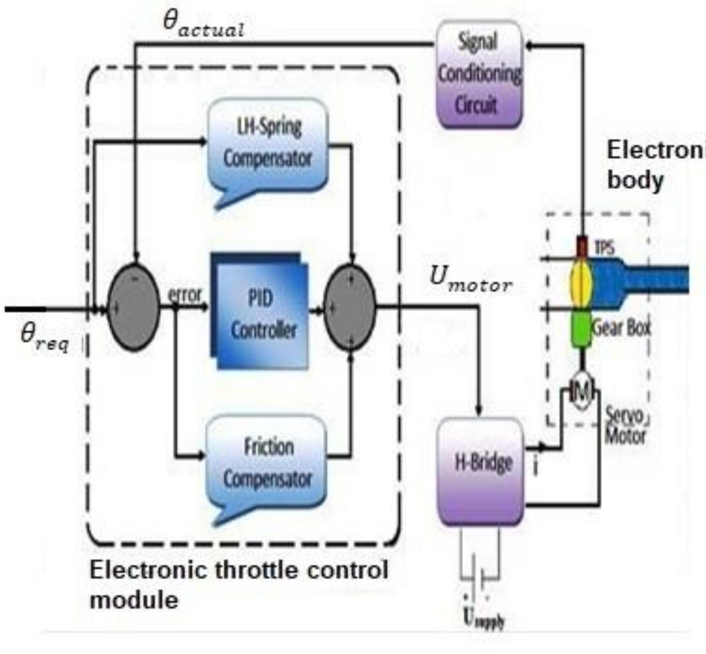

Figure 5.1. Proposed schematic of electronic throttle control system

5.1 Control System Structure of Electronic Throttle Body

The electronic throttle control system includes the accelerator pedal, Electronic throttle control module, and Throttle body. Based on the throttle angle requirement from the estimation module, the throttle control module has to adjust the position the throttle valve by considering the actual position (Θ_{actual}) of the valve by means of the throttle position sensor (TPS). There is a position error of throttle valve (Θ_{req}-Θ_{actual}) due to the nonlinear behavior of the spring and friction characteristics in the throttle body, hence PID based closed loop control system along with compensators as shown in Figure 5.2 is followed for maintaining the throttle angle using the throttle position sensor signal act as a feedback. From feedback input the error value is calculated and fed to closed loop PID controller for adjusting the throttle valve to the desired set point.

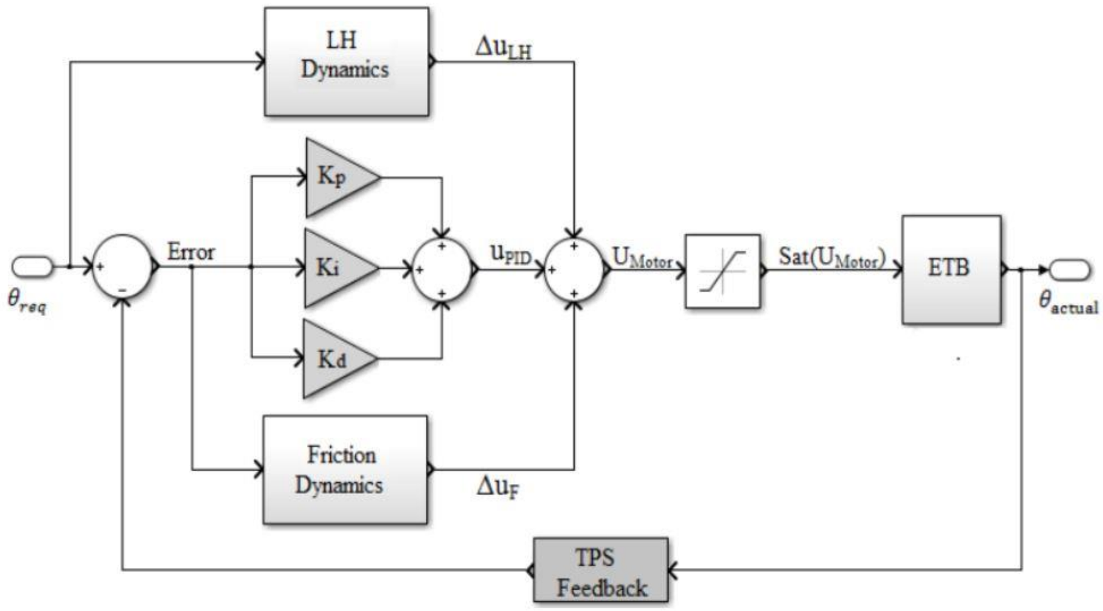

Figure 5.2. Electronic throttle body control system module with compensators.

5.1.1 LH spring compensator

In the limp home dynamic region of the throttle valve, the initial torque is non-zero and there will not be any spring force acting because of the dual return spring. When the throttle is moved from mean position, there is a variation in the spring torque which creates the nonlinearity in the system. To eliminate the non- linearity created by the dual return springs at the limp home position, a feed forward compensator was developed based on the spring model. Gain compensation is provided based on various reference throttle angle at the given limp home position.

$$\Delta_{ULH} = \frac{T_{spring} \times \theta_{req}}{K_{motor}} \tag{5.1}$$

The spring torque compensation is calculated based on the different reference throttle angle using the different cases mentioned in Eq. (4.6). Hence the compensated voltage (Δ_{ULH}) as shown in Figure 5.3 is given in Eq. (5.1), and Km gives a relation between motor stall voltage and corresponding stall torque. The resulted spring compensation voltage is feed forward into the throttle body system.

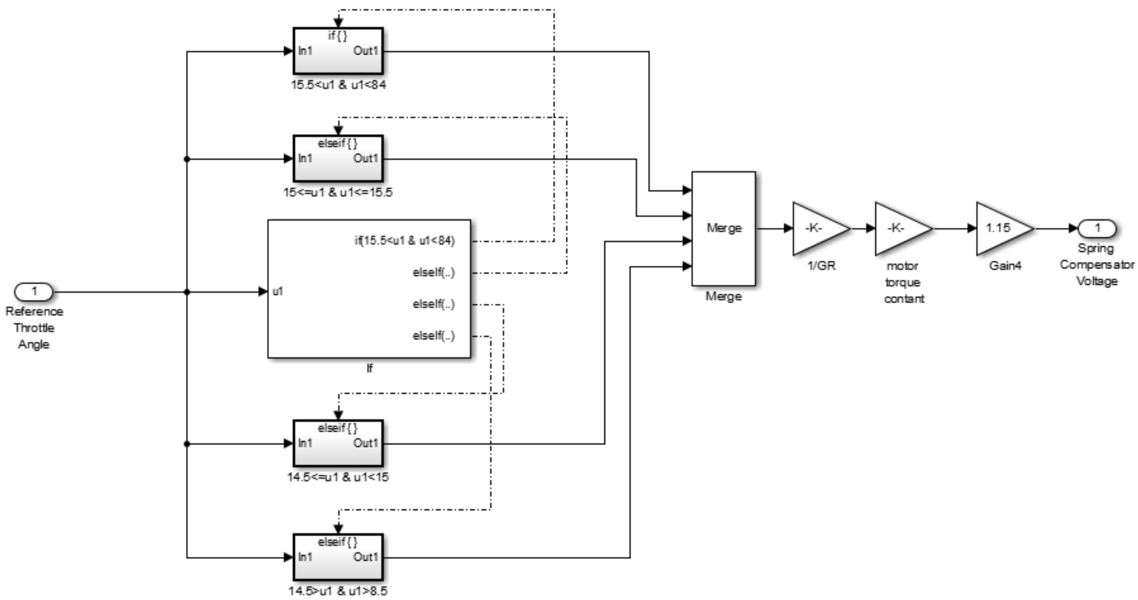

Figure 5.3. Limp home spring compensator for voltage.

5.1.2 Friction compensator

Throttle plate creates a frictional torque (T_{static}) which opposes the direction of motion of butterfly valve while opening or closing. Unlike viscous friction which is a linear function, dry friction has to be compensated because of its nonlinear relationship due to the change in the direction of the throttle. Based on the angular velocity in the model, the friction value and sign are determined in the system. Hence, the parameters such as the throttle angle error, direction of throttle valve, and angular velocity are used for the estimating the friction compensation voltage (Δ_{UF}) as shown in Figure 5.4 which is given in Eq. (5.2). The corresponding voltage is feed forward into the control system which will provide a smooth compensation, to compensate the effects of friction in the system.

$$\Delta_{UF} = \frac{T_{static} \times \theta_{error}}{K_{motor}} \tag{5.2}$$

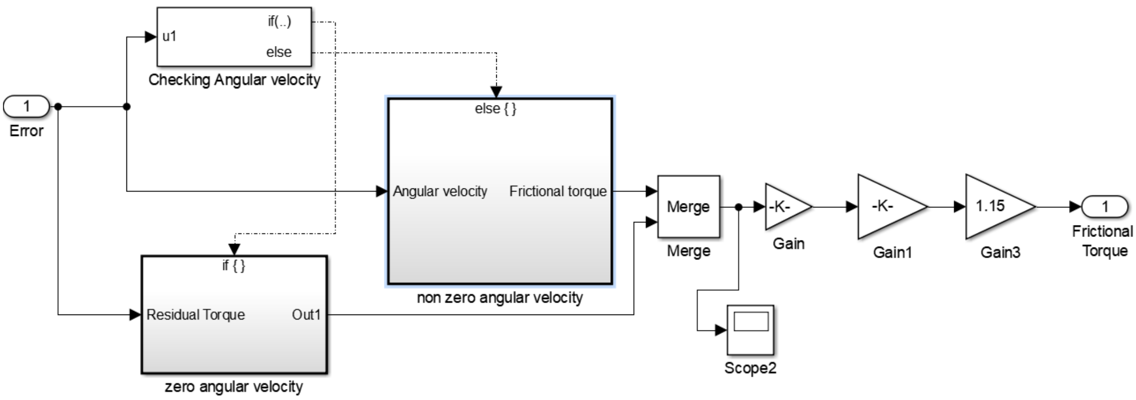

Figure 5.4. Friction compensator for voltage.

5.1.3 PID Controller

PID controllers are found in a wide range of applications for industrial process control. Approximately 95% of the closed loop operations of industrial automation sector use PID controllers. PID stands for Proportional-Integral-Derivative. These three controllers are combined in such a way that it produces a control signal. As a feedback controller, it delivers the control output at desired levels. A close loop system is also known as feedback control system as shown in Figure 5.5 and this type of system is used to design automatically stable system at desired output or reference.

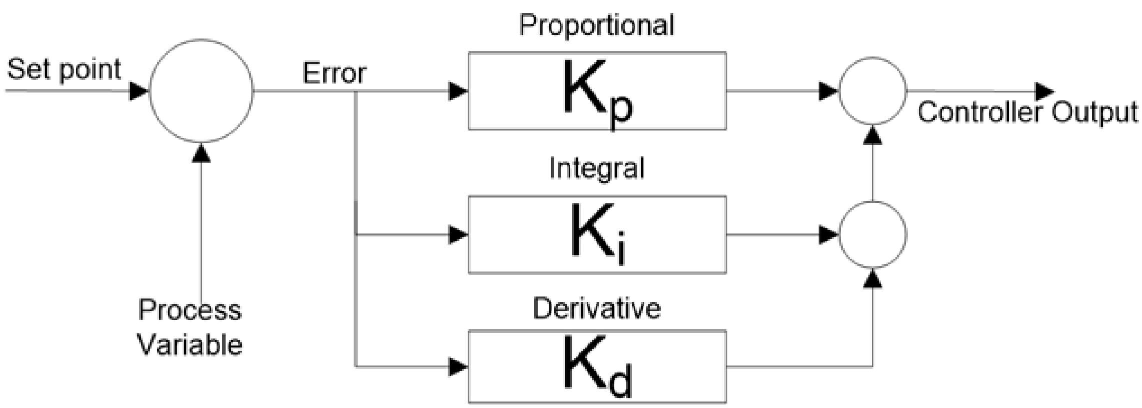

Figure 5.5. Structure of PID controller

For this reason, it generates an error signal. Error signal *e(t)* is a difference between the output *y(t)* and the reference signal *u(t)*. When this error is zero that means desired output is achieved and in this condition output is same as a reference signal. PID controller provides the required correction (U_{PID}) by comparing the required throttle angle with the actual value obtained from the throttle position sensor and it continues till the required throttle angle is achieved by minimizing the error between the required and actual throttle angle values referred from (Jiao et al.,2014). The tuning of the PID is accomplished through the Ziegler-Nichols method, in order to give the better stability in the control system which is given as in Eq. (5.3),

$$\boldsymbol{U_{PID} = K_p(\theta_{req} - \theta_{actual}) + K_1 \int_0^1 (\theta_{req} - \theta_{actual})dt + K_D \frac{d}{dt}(\theta_{req} - \theta_{actual})} \quad (5.3)$$

The final control system output voltage (U_{motor}) to the motor in the electronic throttle system as shown in Figure 5.2 is the summation of the compensating voltages from limp home and friction compensators along with output from the PID controller (U_{PID}) as in Eq. (5.4),

$$\boldsymbol{U_{motor} = U_{PID} + U_{ULH} + U_{LF}} \quad (5.4)$$

CHAPTER 6

RESULT AND DISCUSSION

A SIMULINK model for the proposed control system is developed as shown in Figure 6.1 and a simulation study has been carried out to study the response of the throttle body for the step and sine wave input signals using for software in loop (SIL) simulations and the results are presented in the following sections.

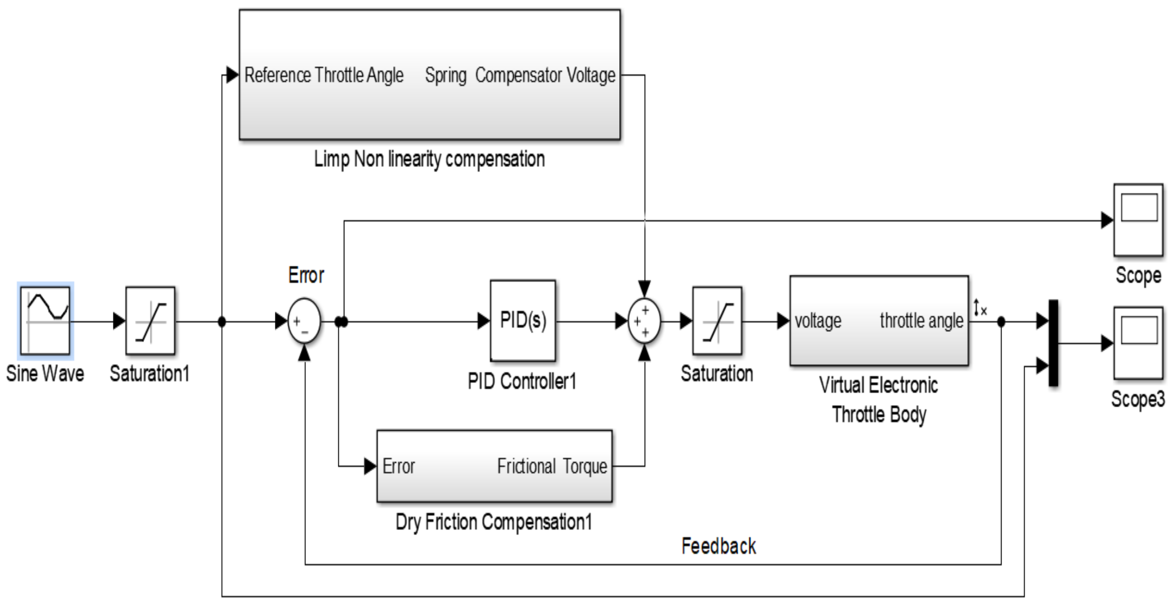

Figure 6.1. Model of the proposed electronic throttle control system

6.1 Parameter Estimation of Electronic Throttle Body

The various parameters in the mathematical model of the electronic throttle body such as motor constant, spring constant, preload torque, etc. have to be estimated for the simulation and optimization of the electronic throttle body control system. In order to establish the various parameters of the throttle body, parameter estimation toolbox in MATLAB is used in this work. For the initial software in loop simulation of virtual throttle body, the parameter values referred from work done by (Loh et al.,2013) are used for SIL. Hence the estimated parameters in Table 6.1 is used for the proposed control system design of the electronic throttle body.

Table 6.1 Estimated parameters of the electronic throttle body.

Parameters	**Symbols used in model**	**Input values**	**Units**
Resistance on Motor	R_m	1.15	Ω
Coulomb frictional torque	$T_{coulomb}$	0.284	Nm
Back EMF constant	$K_{back\ emf}$	0.383	Vs/rad
Inductance on Motor	L_m	1.5	mH
Motor torque constant	K_{motor}	0.383	Nm/A
Equivalent moment of inertia	$J_{equivalent}$	0.0021	Kg. m^2
Equivalent viscous friction coefficient	$C_{equivalent}$	0.0088	Nm.s/rad
Preload torque on spring reverse direction	$T^-_{pre\text{-}load}$	0.0284	Nm
Preload torque on spring forward direction	$T^+_{pre\text{-}load}$	0.158	Nm
Spring constant for reverse direction	K^-_{spring}	0.047	Nm/degree
Spring constant for forward direction	K^+_{spring}	0.0083	Nm/degree

6.2 Performance of the Proposed Control System

The performance of the proposed control system against the nonlinearities such as friction and limp home spring position is examined for the sinusoidal and step input signal. The response of throttle body with the compensators for limp home and friction in the control system is analysed for given input signal and output signal and its proportional error signal results are discussed.

6.2.1 Response of Throttle for the Sine Input

It can be seen that actual throttle angle follows the required throttle angle signal closely with a very marginal error in simulated conditions, as shown in Figure 6.2. There is a step cut in the output response of the throttle body at peak point of the input signal, as the maximum angle of 84.11° to avoid the abnormal behavior of the engine and the minimum angle is found to be 8.3° to avoid the stalling of engine. These results demonstrate the robustness of the proposed control system against nonlinearities such as friction and limp home spring position.

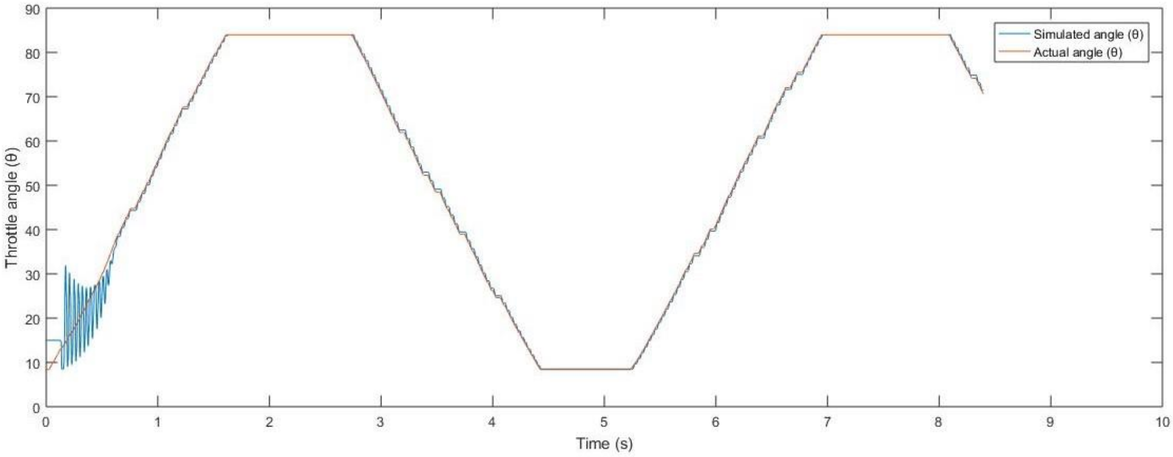

Figure 6.2. Simulated and actual throttle angle for sine input.

Figure 6.3 shows the throttle angle error (Θ_{req}–Θ_{actual}) between actual and simulated conditions, it indicates that there is very small variation in the order of 0.5° variations in the regions other than peak and dip of the required throttle angle response,

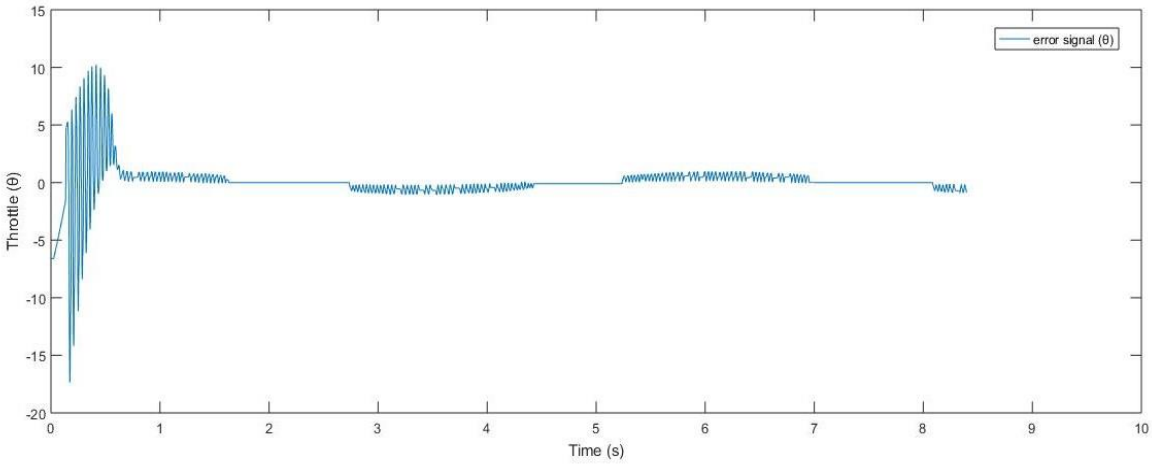

Figure 6.3. Error angle for sine input.

But the error during the peak of the required throttle angle is in the range of 1.15° and during the dip is in the range of 1.3°. Simulation has been done for sinusoidal input it represents the gradual increase of throttle angle caused by accelerator pedal

6.2.2 Response of Throttle for the Step Input

Variation of the actual throttle angle for step signal-based driving cycle input to the position control is shown in Figure 6.4. Driving cycle throttle angle input is varied in step sequence from 0° to 90°. However, the variation of actual throttle is higher for the control system with compensators in the lower region of 8° to 15°. This is due to the default position angle and limp home position spring. Since, the initial spring torque has to be overcome by the throttle movement creates the nonlinearities in the operation.

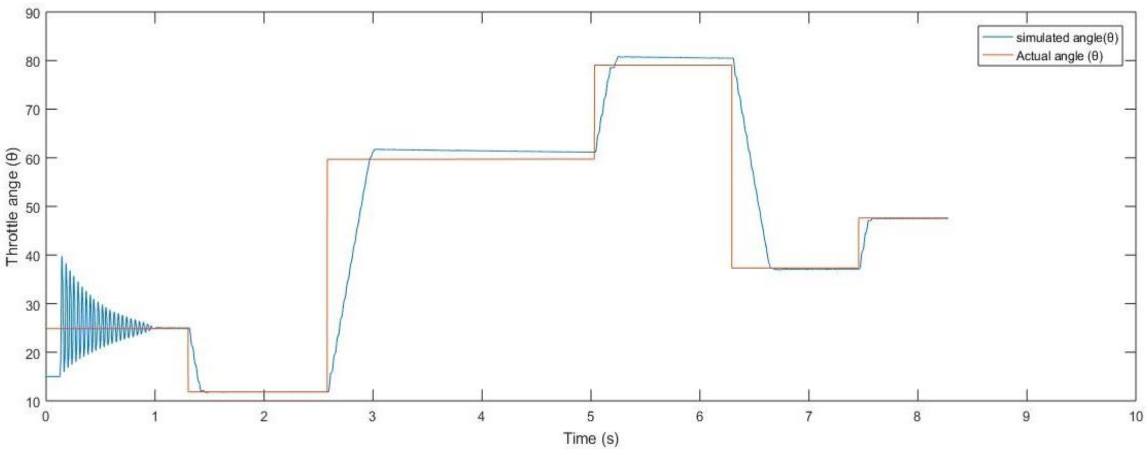

Figure 6.4. Simulated and actual throttle angle for step input

Figure 6.5 shows the throttle angle error (Θ_{req}–Θ_{actual}) between actual and simulated conditions, it indicates that there is error during the peak is in the range of 48° and error during dip is in the range of 42°. This more error caused due to sudden transition input step angle to the system.

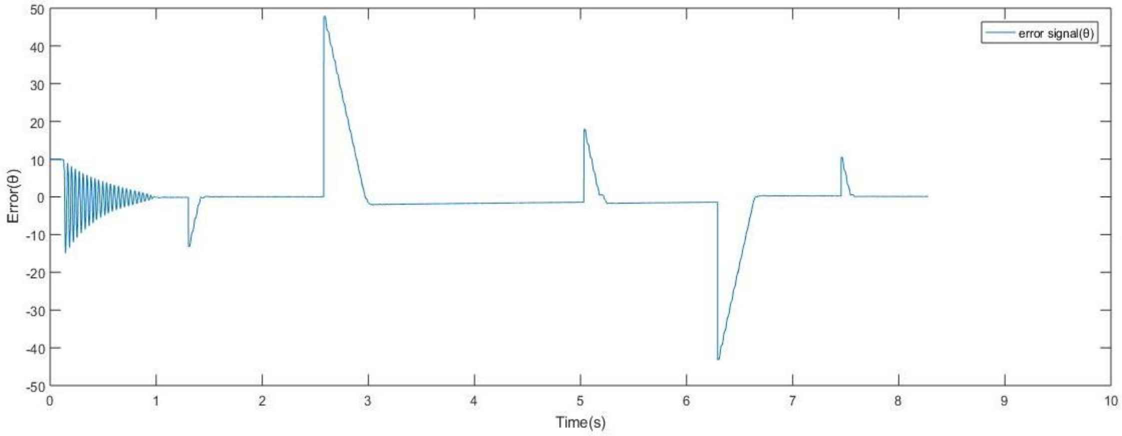

Figure 6.5. Error angle for step input

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

The work presented in this project discuss the pedal follower method for estimation of throttle angle required for the given torque demand. In the proposed control system, the complexity in controlling the electronic throttle system due to nonlinearities such as friction and limp home spring are reduced by the compensators based on the mathematical models developed. Though there were many new controllers are available, PID was adopted because it performs the control action in continuous manner and simple.

From the performance result graphs, it is shown that PID controller with compensators for controlling the electronic throttle body is easy and less complex in compared with other control methods. Based on the error result graphs, it is found that this control method is suitable for gradual acceleration as well as sudden acceleration and produced lesser error. The throttle angle error value was found to be very marginal to the system.

Performance of the control system with compensators was tested using step, sinusoidal input signals and the results conclude that the designed control system has the ability to follow the input throttle angle for simulated conditions.

7.2 FUTURE SCOPE

Controlling an engine based on its nonlinear output behavior is a challenging task. By developing a smart control technology for EMS adapting to the driver behavior, road conditions and atmospheric conditions. On real time application of the advanced control techniques, it will provide an efficient and superior performance of the system.

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