ISSN 2395-1621

Cold Star Emission for an E85 Engine Using Aquino Model

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ABSTRACT

BS-V is a set of regulations among all Indian states dedicated to reduce the negative environmental impact of automobile emissions while maintaining standard vehicle operation. The planned E85 (85% ethanol and 15% gasoline) internal combustion engine for the vehicle produces harmful emissions during its cold startup. Previous research has shown that the majority of unwanted emissions from modern vehicles occur during engine cold starts. The inability to control the stoichiometric air fuel ratio from transient fuel dynamics as the engine warms is a major cause of these emissions. The purpose of this study was to create an engine control algorithm that compensates for the transient fuel dynamics during a cold start. The algorithm will be developed by determining fuel dynamic parameters describing the fuel evaporation time constant (τ) and fraction of liquid fuel entering the engine intake manifold (X).The fuel dynamic parameters are determined from comparing the exhaust air fuel ratio traces with step input perturbations of injected fuel. Because the fueling dynamics depend on temperature, engine speed, and manifold air pressure, the data from perturbation testing was collected over several engine speeds and manifold pressures during the engine's cold start.Lookup tables of τ and X parameters for different engine operating conditions were created and will be implemented into the engine control unit (ECU) to compensate the transient fueling. The research will help achieve the goals of the BS-V to reduce the vehicle's environmental impact while maintaining standard operation. The procedure to create the algorithm can be implemented to control emissions of production E85 vehicles

ARTICLE INFO

Article History

Received :29th February 2016

Received in revised form :

1st March 2016

Accepted : 4th March 2016

Published online :

6th March 2016

I. INTRODUCTION

Developing cleaner and more efficient vehicles is a pressing need for the future of the automotive industry. Since the late 1960s, the U.S. government has regulated harmful vehicle emissions for health and environmental concerns. Since 1980, the accumulation of increasingly rigorous emission control has reduced emissions by 19% in the United States [1]. Current BS-IV vehicle emissions regulations and proposed BS-V regulations have accelerated automotive research in vehicle efficiency and emissions reduction technologies.The available powertrain consists of a 1.8L Honda compressed natural gas (CNG) engine modified for E85 (85% ethanol and 15% gasoline) and two Parker-Hannifin electric machines powered by a battery pack. The advanced powertrain will be built to operate in charge depleting or charge sustaining modes depending on the battery charge and vehicle operation. During the charge sustaining mode, the engine will be required to power the vehicle or charge the batteries which leads to emissions production.

We have chose an E85 powered 1.8L Honda engine for several advantages. First, the engine has a high compression ratio of 12.5 to run on CNG. This higher compression ratio improves the engine's fuel conversion efficiency. Second, E85 fuel has significant tailpipe emissions reductions in nitrous oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO) compared with engines[2]greater octane rating than gasoline permitting the engine to run at a high compression ratio without inducing knock. Finally, the engine features several advanced features such as variable valve timing and adjustable intake runners for improved efficiency.Tailpipe emissions primarily consist of NO_x, HC, CO, nitrogen dioxide (N_2), carbon dioxide (CO_2), water (H_2O), hydrogen (H_2), and oxygen (O_2). The harmful tailpipe emissions of NOx, HC, and CO, however, are the emissions of most interest. Most modern vehicles feature a three-way catalytic converter on the vehicle's exhaust and control methods for air and fuel flow to reduce these emissions.

II LITERATURE REVIEW

Cold start Engine Emissions

The engine start-up process from a relatively cool temperature to its steady operating temperature has been known to cause high emissions. This process, known as an engine cold start, is defined as an engine start from ambient room temperatures around 20-30°C or lower [6].Until the engine reaches a controlled steady state temperature after 1 to 2 minutes, the emission output will be of much greater magnitude than any other time of engine operation.

In modern engines, fuel injectors are used to inject fuel with precise timing into the intake manifold. The fuel enters the engine's intake manifold close to the intake valve of the cylinder. The fuel enters the manifold as a partially evaporated and partially liquid mixture. The evaporated fuel enters into the cylinder immediately when the intake valve opens. The liquid fuel, however, forms fuel puddles in the intake manifold. The manifold close to the engine cylinder is warm and causes the liquid fuel to evaporate over time. Both the rate at which fuel evaporates and the composition of fuel entering the manifold depend on several engine operating conditions including engine temperature.

During the engine cold start process, the fuel rate that actually enters the cylinder changes as the engine warms. Because the fuel rate that enters the cylinder is not the commanded fuel rate of the injectors, the air fuel ratio cannot be accurately controlled to achieve stoichiometry. The changing fuel rates that actually enter into the engine cylinder during cold starts are what define transient fuel dynamics.

The main focus of this research is to reduce the criteria gas emissions of CO, NOx, and unburned and partially burned HC. Particulate matter from spark ignition (SI) engines is generally ignored as they are much less in comparison to compression ignition (CI) engines SI engine pollutant, CO is formed from the incomplete combustion of excess hydrocarbons with air and from high temperature combustion. NOx is caused primarily from reacting N2 and O2 species at high cylinder temperatures. NMOG consists of total hydrocarbons (THC) and organic gasses leaving the tailpipe excluding methane [4]. Hydrocarbon emissions come from partial burning of fuel or from fuel that escapes the combustion process in the cylinder.

Aquino Model

Aquino was the first to create a model in 1981 to describe the physical nature behind transient fueling. His model incorporates an evaporation time constant, τ, and a variable to describe the fraction of liquid fuel entering the cylinder, X. He applied the conservation of mass to describe the fuel puddle or "film" in the intake [8]. The rate of vaporized fuel was described with the X parameter [8]. The actual rate of fuel entering the cylinder is a combination of the fuel rate leaving the puddle to create equation.

III EXPERIMENTAL EQUIPMENT

The experiments occurred with a four-quadrant, 200 hp DC dynamometer from a safe control test cell. The dynamometer was used with constant speed control during engine testing. The engine used was a 1.8L, 4-cylinder Honda engine converted to run on E85 fuel. The engine's Woodward engine control unit (ECU) in connection with ETAS INCA software was used to collect desired engine data

Engine Instrumentation

The engine is monitored by its control unit with numerous sensors. When desired, the data can be sent from ECU for analysis ETAS INCA software was the data acquisition system used to obtain readings from the ECU and control the experiments.

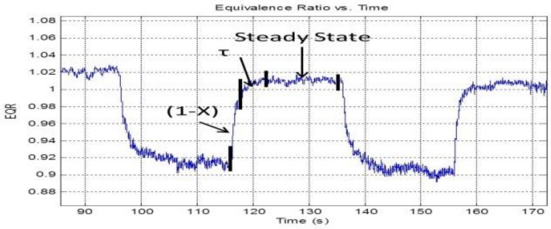
Data Acquisition and Software

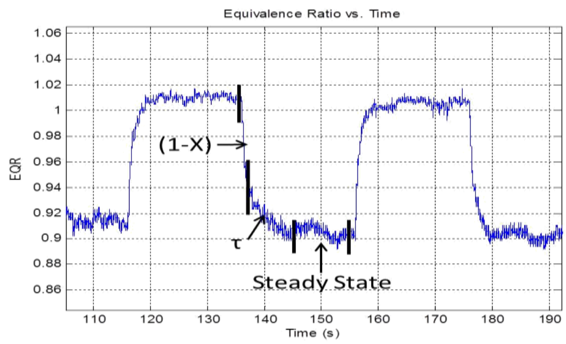
ETAS INCA software was used to collect sensor data from the Woodward ECU. The INCA software allows the user to both visually observe and collect desired data from a workspace on a laptop. The INCA software was used to initialize engine operation after the engine bay had been prepared for testing. Control features in the INCA software permit the user to modify engine operation parameters such as throttle percentage or fuel flow rate. The fuel perturbation testing in this experiment was controlled and initialized through INCA.The software developed to control the engine was created in MATLAB's Simulink with both Simulink and MotoHawk models. MotoHawk is an application which permits a user to develop block diagram engine models in Simulink. The created models can be uploaded onto theWoodward ECU with Mototune flash programming in a short time frame.

IV. EXPERIMENTAL PROCEDURE

Testing Methodology

To accurately determine the τ and X parameters of the Aquino model, a testing procedure must be implemented to clearly observe and determine the fueling dynamics. The most common method for collecting fuel dynamics data is through the use of the perturbation method described below. This method is used to determine τ and X parameters from pre-catalyst EQR traces. Figures below demonstrate how the τ and X parameters affect the EQR response data for up and down perturbations. The fraction of evaporated fuel (1-X) results in a close to instantaneous "jump" in EQR. The τ parameter is then determined from the approxima1st order response in EQR until it reaches a steady state value.





To make a greater impact on emissions reduction, a "map"of τ and X data is desired over a range of common engine operating conditions. It is known that τ and X are functions of engine speed, MAP, and temperature. The τ and X parameters were decided to be determined at a set engine speed and MAP from an engine cold start near room temperature until the steady state operating temperature of 80°C. Engine speeds of 1000 RPM, 2000 RPM, and 3000 RPM were used vs. MAPs of 30 kPa, 60 kPa, and wide open throttle (WOT) for nine total engine tests. The MAP for the low load and 1000 RPM case was set to approximately 40 kPa instead of 30 kPa to ensure that the engine would not stall.

Data Collection

The software in the engine's ECU had a previously created model for fuel perturbation testing. The user has the ability to enable the model and determine the frequency and the percent amplitude of square wave fuel injection above and below stoichiometry.

It was determined that the fuel perturbations were to be set at ±5% of the stoichiometric air fuel ratio with a frequency of 0.05 Hz for 20 second perturbations. The 5% air fuel ratio perturbation was used because limiting emissions during experimentation was desired and larger perturbation amplitudes values tend to create nonlinearities [10]. The frequency was set to 0.05 Hz to ensure that the fuel dynamics reached steady state by the end of each perturbation especially in low speed and low MAP cases.

Experiment Resuls

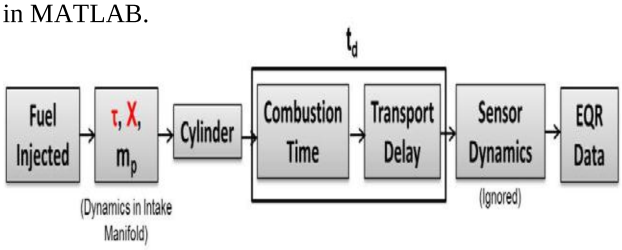
τ AND X DETERMINATION

In order to determine τ and X from collected data, the effects from the flow path of the fuel injected to the exhaust must be considered. We demonstrates this flow path and parameters in addition to τ and X that relate the fuel rate injected to the EQR. These parameters are the initial mass of the fuel puddle (mp) and the total transport time delay(td)

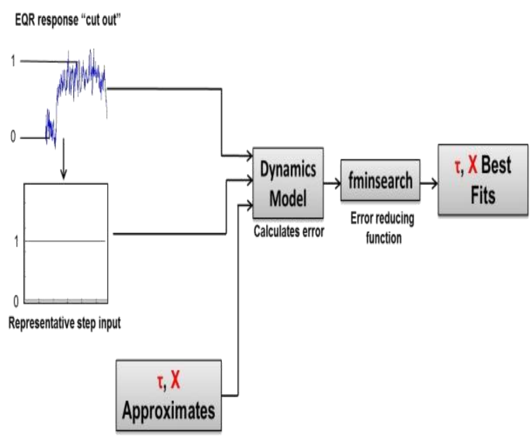
Modeling Technique

Methods to determine τ and X often involve a model with the parameters that describe the fuel and exhaust flow. One method creates a fuel dynamics model that sends the fuel rate injected and guessed parameter values as inputs. The model modifies the parameters to achieve a best fit with calculated cylinder fuel rate from the EQR and mass air flow (MAF). The equation to determine the calculated cylinder fuel rate is shown below. The data returned from this modeling technique is not always accurate because the additional parameters make fitting difficult.Part of the methods used in this research involves a similar modeling technique. This modeling method tries to approximate τ and X with greater accuracy by eliminating the mp and td parameters. The td parameter is eliminated by using a MATLAB script with the ginput function to "cut out" each perturbation to be sent into the model. Cutting out the perturbation allows the user to pick the start and endpoint of the EQR trace perturbation and match it with the corresponding data point in the fuel rate injected. The calculated fuel rate entering the engine differs from the fuel rate recorded. This is because the ECU returns the commanded injected fuel rate, but the actual fuel rate injected is slightly different. Also, not all of the fuel is burned in combustion or reaches the exhaust sensor. This error is eliminated by normalizing the EQR trace from 0 to 1. The normalized trace is used to determine a theoretical step fuel input of 1 for an up perturbation or 0 for a down perturbation. Finally, a "normalized" initial mass puddle is determined by solving Equation for the puddle mass with the first normalized EQR and fuel rate injected values.

The modeling technique used differs from others in the way it estimates τ and X. Instead of approximating τ and X by fitting the calculated cylinder fuel rate with an approximate cylinder fuel rate, the technique varies τ and X so that the sum of the error between the calculated cylinder fuel rate and the approximate is a minimum. The function used to find this minimum error is the fminsearch function in MATLAB.



INITIAL METHOD

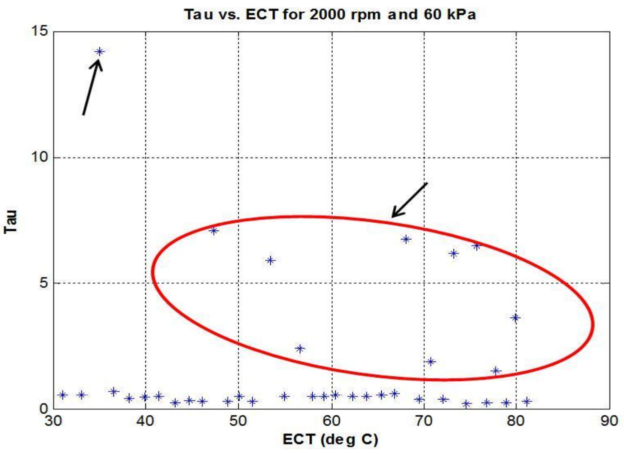


An initial MATLAB script file was created for each of the nine perturbation experiments utilizing the modeling technique described above. Sample code for the 2000 RPM and 60kPa experiment made below

Two Simulink models describing the fuel dynamics were run by the script file. The models were developed to solve the fuel dynamics equations more easily instead of using MATLAB code. The first Simulink model was run through the fminsearch function to return an error value. This model and its subsystems are shown as Figures 9:4 through 9:6 . The second Simulink model was nearly identical to the first except its output returned the calculated cylinder fuel rate with τ and X to compare with the experimental cylinder fuel rate and the theoretical step input. This model is shown below.

Initial τ and X Results

The previously described methods were used to determine the τ and X results for each of the nine perturbation experiments. Figure shows a sample of τ data for the 2000 RPM and 60 kPa case. The arrows show data outliers from the expected results. The remaining points appear to follow similar to expected results. Figure 5:4 shows a sample of X data for the 2000 RPM and 60 kPa case. The X data has no discernible trends. Similar trends occurred for the other engine speed and MAP cases as well. A new methodology was needed to better approximate X values.



Initial Methodology Issues

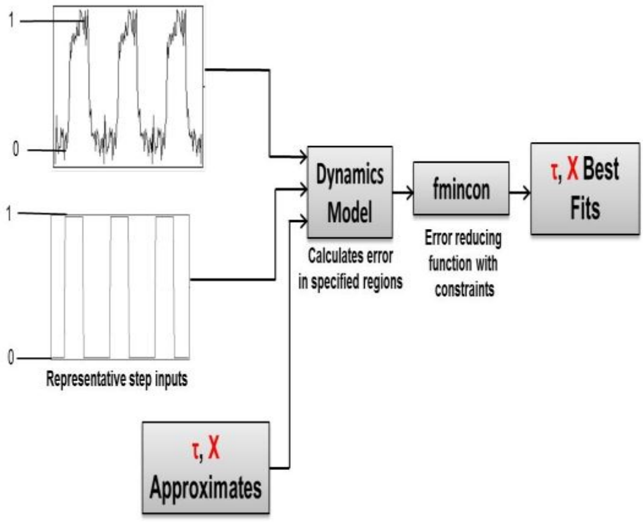
After observing the initial results, the primary issues with the first method were reviewed

First, the code evaluated error over the entire EQR response where τ and X no longer had an effect on the response. Second, the fminsearch function picked unreasonable τ and X values which would cause the calculated fuel rate to diverge, and the code would stop functioning. Finally, the code was returning some expected τ value trends but not X values

Second Method

The second method used to determine the τ and X parameters addressed the initial methodology issues. This method normalizes adjacent up and down perturbation cut outs and repeats them over several cycles with a repeated sequence block on Simulink. The initial dynamics model was updated with logic to limit error evaluation only where τ and X affect the response. This was accomplished by evaluating error when the calculated response was between 0.05 and 0.95. The model also has logic to reinitialize error evaluation over the entire experimental response if the calculated response escapes values above 2 or below -1. This prevents the possibility of a diverging calculated response. The fmincon function was used to constrain the τ and X parameters within reasonable values to also prevent diverging responses.

Figur shows a pictorial representation of the methodology. A second method code sample is presented in Appendix C, and the updated Simulink model is shown in as Figure



V. CONCLUSIONS AND FUTURE WORK

This research successfully demonstrates methods to reduce cold start emissions from transient fuel dynamics. A model of the fuel dynamics was used several times to determine the τ and X parameters. Several different methods were utilized to determine the most accurate results. More data points, especially at high engine speeds and MAPs, are needed to verify expected trends. Current τ and X data is lumped into four total fit curves to ensure anticipated trends with more data points. A working fuel compensator algorithm has successfully been completed and can be implemented into the engine code for use or for testing purposes.

Several forms of future work are planned. First, more testing is desired for more accurate

τ and X data for the various operating conditions. A more accurate compensator will have two 3-D lookup tables for τ and X as functions of engine speed, MAP, and temperature. Second, heated fuel injectors will be implemented onto the Honda engine, and the process for creating a transient fuel compensator will be repeated for HFIs. The goal is to determine if the heated fuel injectors will require different fuel compensation parameters from the regular fuel injectors. Finally, an analysis on the emissions reduction after the fuel compensator has been implemented is desired.

My future plans are to attend Ohio State this upcoming school year and pursue a Master's Degree in Mechanical Engineering. I intend to continue automotive related research particularly in power train related topics.

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