

Purge Modeling for New Propulsion System Technology Applications

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ABSTRACT

This paper presents a purge system model developed for hybrid electric vehicle (HEV) applications. Assessment of purge capability is critical to HEV vehicles due to frequent engine off operation which limits carbon canister purging. The purge model is comprised of subsystems representing purge control strategy, carbon canister and engine plant. The paper is focused on modeling of the engine purge control feature. The purge model validation and purge capability predictions for an example HEV vehicle are presented and discussed.

INTRODUCTION

Purge capability predictions are increasingly important for new propulsion system technologies such as HEV vehicles - micro hybrid Start/Stop, mini and full hybrids, GTDI engines, TI-VCT engines, VD engines, etc. The need of such modeling is due to the complexity of future powertrain applications and specifics of operation which limit purge system capabilities. Some of the examples of purge limiting factors are: a) engine shut down events at hybrid operation; b) boost phase of GTDI engine operation. Both above factors reduce the period when engine manifold vacuum is available for carbon canister purging. The purge system modeling tool described here allows the system designer to predict the purge capability for new applications and properly size/design evaporative systems.

In previous work [1], a one-dimensional carbon canister adsorption model (CANMOD) has been developed to assist in the prediction of the performance of carbon bed canisters in vehicle evaporative emission control systems. The model accounts for mass and thermal phenomena, both of which are found to be essential in accurately predicting canister

behavior. A one-dimensional computer model of the carbon canister was developed and validated with experimental data.

A control oriented purge system model has been described in [2]. The proposed purge control system utilizes a gasoline vapor concentration sensor to measure the concentration of fuel vapors purged into the engine. The compensation algorithm to calculate a desired flow of purge fuel vapor into the engine is based on accurate modeling of the purge flow in purge lines, engine manifold delay and idle fuel injector PWM limitation.

The papers [1,2] are focused on modeling of specific components of the purge system, e.g. canister [1] and purge valves [2]. The purge modeling effort presented in this paper is focused on purge system assessment for new powertrain technologies with emphasis on engine purge control strategy. This effort is aligned with the Vehicle Model Architecture (VMA) used at Ford Motor Company to support model-based Vehicle System Control design work [3]. The purge control feature model and carbon canister model are integrated as new components, while engine plant and vehicle models are reused from existing applications.

Developing a purge system model is a very challenging task due to the multi-domain nature of the purge system including purge control and the fuel vapor release/absorption process in the carbon canister. The basic requirements for a purge system model include ability to capture essential system dynamics such as purge fuel fraction estimation, purge control code transient behavior and interaction with the vehicle level control. Also the purge model must be computationally efficient to allow full drive cycle analysis. The latter requires development of a control oriented carbon canister model and a simplified model of the purge algorithm

which can operate with major engine inputs available from fuel economy type engine plant models.

The purge system model described here features a carbon canister model which predicts the purge fuel fraction given engine operating conditions and purge history. The carbon canister model is calibrated from vehicle or canister bench tests. Calibration based on vehicle tests reflects the as-installed in-vehicle evaporative system (EVAP) operation while calibration from bench canister tests is more suitable for predicting purge system performance with new canister designs.

The purge control model relies only on major engine plant inputs to predict purge flow command. The model is populated with in-vehicle purge control feature calibration tables to better represent the specific behavior of the purge algorithm implementation. This provides the means for accurate purge air and fuel transient flow prediction.

PURGE MODEL PARTITION

The purge system model is partitioned into the following major subsystems representing

- Engine plant
- Evaporative system
- Purge control feature

Figure 1 shows a top level view of the purge model and the major interfaces between subsystems.

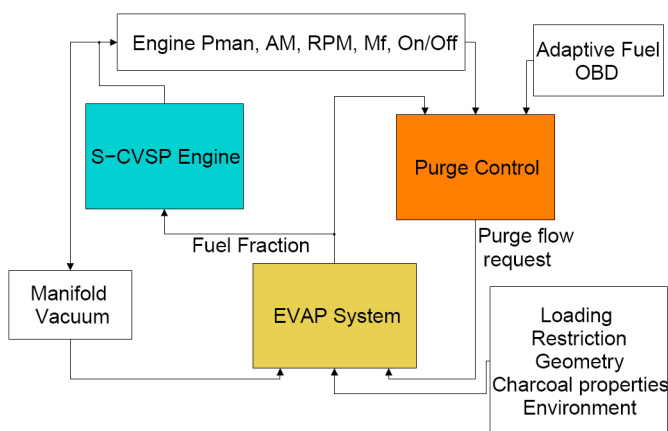


Figure 1. Top level decomposition of the purge model.

The Simulink-Corporate Vehicle Simulation Program (S-CVSP) engine model provides the main engine signals required by the purge control model:

- Manifold vacuum
- Speed
- Air flow

- Engine on/off command
- Fuel per injection

The inputs to the S-CVSP engine model are purge flow and purge fuel fraction which are used to adjust the engine fuel per injection.

The evaporative system model calculates the actual purge flow through the canister and the purge flow fuel fraction delivered to the engine. The main inputs to the EVAP system model are:

- Engine manifold vacuum
- Purge flow request

The EVAP system model is control oriented and it relies on loaded (fully charged) canister characterization from vehicle and/or bench tests. The canister model calculates purge fuel fraction and actual purge flow based on a set of canister maps.

More complex, physics-based EVAP system models can be developed with different levels of detail such as:

- Canister loading
- Geometry of the canister
- Charcoal properties
- System restrictions
- Environmental conditions

Such models are typically too computationally intensive for drive cycle simulation and desktop control calibration work. No further discussion is given here.

The Purge Control feature model calculates a purge flow command based on inputs from the engine and carbon canister models. It is a Simulink model of the main functionality of the purge control code implemented in the engine control strategy.

Additional inputs to the Purge Control Model are the following engine interactive monitor flags:

- Adaptive Fuel
- Intrusive on-board diagnostic (OBD)

The purge flow is not allowed during adaptive fuel or OBD intrusive monitors activity.

The purge model was integrated into the S-CVSP modeling environment according to the VMA modeling guidelines [3]. The purge control model has been integrated as a part of the powerplant module controller and the EVAP system model

has been included in the powerplant plant subsystem. Figure 2 shows a top level view of the vehicle model architecture (VMA) in Matlab/Simulink.

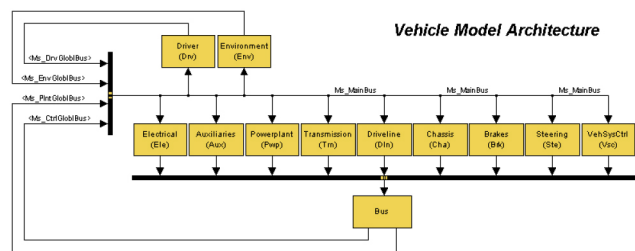


Figure 2. Top level implementation of the VMA.

PURGE CONTROL MODEL

The purge control model represents the main functionality of the engine purge control feature. In the vehicle, the purge control feature estimates the purge flow fuel fraction based on a UEGO sensor signal. The UEGO signal is not available from the simplified engine model that is part of the framework shown in Figure 1. Therefore, the purge fuel fraction is calculated in the carbon canister model using canister calibration maps.

The Adaptive Fuel and Intrusive OBD Monitors are engine control features that have higher priority than the purge control feature and they shut down purge flow when active. These external control features that interact with purge control have very complex logic and require many additional input signals not available in the Purge System Model framework (Figure 1). Therefore, highly simplified representations of Adaptive Fuel and Intrusive OBD Monitors have been developed for the purge system model.

The engine purge code was partitioned into major subsystems and emulated as a Simulink model. The model is populated with purge control calibration tables used in the actual engine control unit (ECU) code. Figure 3 shows a top level decomposition of the Purge Control model.

The major subsystems of the purge control model are:

- Purge Ramp Up Rate
- Purge Fuel Desired
- Purge Flow Request Temporarily
- Purge Flow Request

The Purge Ramp Up Rate subsystem calculates the rate of change of the purge flow. The main inputs to the subsystem are:

- Engine air flow
- Purge fuel fraction
- Purge flow request

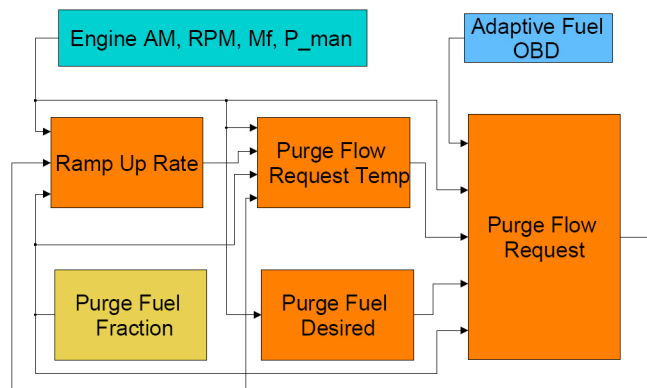


Figure 3. Top level decomposition of the purge control model.

The ramp up value is calculated as a product of the outputs of three look up tables with inputs: engine air flow, purge flow request, and purge fuel fraction. Initially, the purge ramp up value is reduced until the purge flow request is above a given threshold over a specified period of time. Once this condition has been met, it is assumed that the purge algorithm has learned the purge fuel fraction and the reduction factor can be removed.

The HEV purge strategy can use a much more aggressive calibration than a comparable conventional vehicle because the HEV engine typically operates under higher load conditions with high combustion stability. Also, in a HEV, the driver demand can be allocated to the electric traction motor for a short time to prevent engine stalling.

The Purge Flow Request Temporary subsystem calculates the preliminary purge flow request. The main inputs to the subsystem are:

- Purge ramp up rate
- Purge flow request (from previous control time step)
- Engine speed
- Engine air flow
- Purge fuel fraction

The purge flow request from the previous control time step is incremented by the ramp up rate amount calculated in the Ramp Up Rate subsystem. The purge flow update rate is defined by the td_sec table shown in Figure 4.