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Modular Heavy Duty Vehicle Modelling and User Interface Development

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Abstract: Engine calibration work requires the use of realistic simulation models for designing and testing powertrain control algorithms in offline simulations before hardware-in-the-loop, dynamometer and road testing. These models should be computationally efficient for repeated offline simulation runs. Also, they should have a modular, standardized structure to make it easy for a team of engineers to work on it simultaneously. In this paper, such a modular Simulink model is developed for heavy duty vehicle powertrain dynamics. The model framework is formed using subsystems such as engine, transmission, driveline, vehicle dynamics, auxiliaries, driver, environment, test scenarios, hardware-in-the-loop and analysis. A user interface is developed to ease the model usage and also to analyze the simulation results using plots and previously defined metrics. Well established and widely accepted simulation scenarios such as drive cycle test, performance test, gradeability test, cruise test and coast-down test are coded and integrated into the user interface.

Keywords: Heavy duty vehicle modeling, engine, transmission, driveline, vehicle dynamics, user interface.

1. INTRODUCTION

Advances in heavy duty vehicle control systems can reduce the drivers workload, help prevent accidents, reduce pollutant emissions and also provide fuel economy. The development and test process of vehicle control systems requires access to realistic simulation models. These models should be easily configurable, tuneable and verifiable.

Earlier work on modelling heavy duty vehicles can be found in the literature. An early paper that addressed the problem of longitudinal control design for the automated operation of heavy duty cycles and a longitudinal model is built with a turbocharged intercooled diesel engine and a four speed automatic transmission in Yanakiev and Kanellakopoulos (1995). Heavy-duty vehicle modelling and model based longitudinal control design are considered in Lu and Hedrick (2003) and Lu and Hedrick (2005). In these papers, vehicle dynamics and powertrain and drivetrain components that are modelled include turbocharged diesel engine, torque convertor, transmission, transmission retarder, pneumatic brake and tyre.

In Yang et al. (2006), a heavy duty vehicle nonlinear dynamic model is developed including the engine and the torque convertor and the components of the brake subsystem. Feedback linearization is used to convert the traction and brake subsystems into a linear canonical form. In Fang et al. (2009), coordinated control of three braking subsystems of heavy duty vehicle (the engine brake, the transmission retarder and the pneumatic brake) is proposed to produce the required braking torque with less time delay, overshoot and undershoot.

In this paper, a realistic longitudinal heavy duty vehicle powertrain model is developed considering a modular structure which contains different subsystems reflecting the dynamics of different parts. The model is illustrated using typical simulation case studies. This modular structure makes it easier for multiple users to work on the model simultaneously. A user interface is developed to easily define and perform different simulation case studies. Entering the parameter inputs to the model and the subsequent plotting, comparing and saving results operations can be carried out easily by the help of the user interface. Also, the signal structure of the simulation model is available

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for use in a hardware-in-the-loop system by overriding the main signals.

The rest of the paper is organized as follows. Section 2 presents the main modelling framework of the heavy duty vehicle. Also, the subsystems which constitute the modular structure are given in the subsections of Section 2. The developed user interface is introduced in Section 3. Case studies are explained and some simulation results are given in Section 4. Finally, the paper ends with conclusions given in Section 5.

2. MAIN MODELLING FRAMEWORK

The main framework of the simulation model contains engine, transmission, driveline, vehicle dynamics, auxiliaries, driver, environment, test scenarios, hardware-in-the-loop and analysis subsystems. The modular structure of the simulation (HiL) model can be seen in Fig. 1. The authors were initially inspired by the vehicle model architecture layout formally introduced in Belton et al. (2003) in designing the modular structure in Fig. 1 with a main bus for collecting and sharing important simulation variables. However, as compared to Belton et al. (2003), different subsystem models were built and a different signal flow architecture was developed in the work presented here.

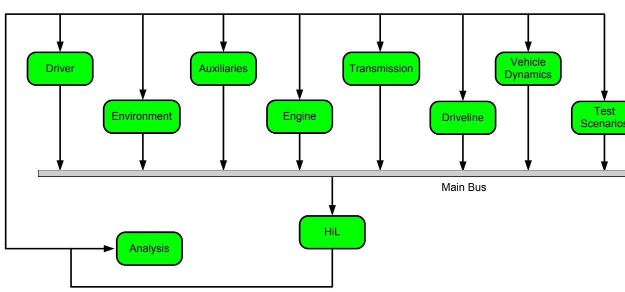

Fig. 1. Main layout of the heavy duty vehicle simulation model

The aforementioned subsystems send their related signals to the main bus (except HiL and analysis subsystems). The main bus signals can be overridden by the HiL subsystem to realize HiL simulations and also all signals can be viewed from the analysis subsystem to investigate the simulation results, once they are available.

In the simulation model, only the longitudinal dynamics model of the vehicle is considered, neglecting the lateral and suspension dynamics of the vehicle. The effect of slipping of the wheels on the vehicle dynamics is also neglected. In general, the model is developed considering torque flow from the engine to the tires and velocity flow from the tires to the engine (in other words, the forward model structure is applied) as shown in Fig. 2.

2.1 Engine Subsystem

The engine subsystem calculates the engine speed and the torque that are transferred to the clutch. The engine emission values are also calculated using look-up tables in this subsystem. The engine subsystem consists of two parts: the engine control system and the engine model.

The engine control system contains the idle speed controller, the engine indicated torque calculation and the engine start/stop block. The idle speed controller sets the engine speed to a predefined idle value according to clutch information from the transmission subsystem. The idle speed controller is designed as a PID controller with an external reset to prevent integrator wind-up. The engine indicated torque is calculated using a 2D look-up table as a function of accelerator pedal position and engine speed.

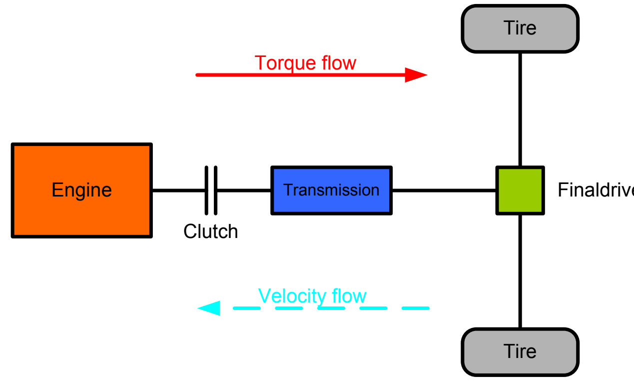

Fig. 2. Simulation model general signal flow

The engine model has two modes changing with clutch transition conditions. These modes are the engine mode 1 (clutch locked) and the engine mode 2 (clutch slipping). It calculates engine net torque, clutch input torque and angular acceleration of the engine shaft and sends all of these signals to the main bus.

The clutch input torque can be calculated when the clutch is locked as follows:

$$T_{clt,in} = \underbrace{T_{eng,ind} - T_{eng,fric} - T_{eng,brk}}_{T_{eng,netout}} - T_{aux,out} - J_{total}\alpha_{eng,out} \quad (1)$$

where $T_{clt,in}$ is the clutch input torque, $T_{eng,ind}$ is the engine indicated torque, $T_{eng,fric}$ is the engine friction torque, $T_{eng,brk}$ is the engine compression release brake torque, $T_{eng,netout}$ is the engine net torque output and $T_{aux,out}$ is the auxiliaries load torque. J_{total} denotes the total moment of inertia containing the moments inertia of the flywheel, crankshaft, clutch and transmission gears. $\alpha_{eng,out}$ is the angular acceleration at the engine output. This value is equal to $\alpha_{trans,in}$ which is the transmission input angular acceleration calculated by the feedback path when the clutch is locked.

The clutch input torque is equal to the clutch reaction torque when the clutch is slipping:

$$T_{clt,in} = T_{clt,reac} \quad (2)$$

In this case, eng,out can be solved using equation (3):

$$\underbrace{T_{eng,ind} - T_{eng,fric} - T_{eng,brk}}_{T_{eng,netout}} - T_{aux,out} - T_{clt,reac} = J_{eng,side}\alpha_{eng,out} \quad (3)$$

where $J_{eng,side}$ denotes the moment of inertia of the rotational parts at the engine side. It contains the flywheel, crankshaft and clutch part at the engine side (which rotate with engine output shaft) inertias.