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MODELING AND SIMULATION OF AN AUTOMOTIVE DRIVETRAIN

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Abstract

In the automotive industry, the maximum performance with minimum compromise is highly desirable and expected from a vehicle's powertrain. This paper concentrates on modeling and simulation of one of the components of powertrain, namely the drivetrain of an automotive vehicle with automatic transmission using MATLAB/Simulink. The model is built in a modular way to facilitate reuse and make the model more well-arranged. This will also increase the possibilities for updates and to make changes in the model. By using the developed model, several tests can be performed in a virtual environment instead of conducting the tests in a real vehicle and thus saves a lot of time. The model enables driving simulations from stand still up to the higher speed domains. When the control unit of the automatic gearbox system reaches an intended gear shifting point, automatic up or downshift will be performed. A detailed mathematical model based on the geometry and dynamics of the components has been formulated and equations of their respective motions representing their behaviour have been derived.

Introduction

An automotive powertrain consists of engine, transmission and drivetrain. In this work a dynamic model of an automotive drivetrain is developed using three states in the continuous time domain by considering the dynamics and kinematics of an internal combustion engine, an automatic transmission and rubber tyres. Much time and cost are necessary to develop the various elements involved in the drivetrain, and one of main concerns is to reduce the time and cost in developing a new drivetrain system. One of the approaches in reducing the development time is to perform digital simulation analysis using the modular programming approach in MATLAB/Simulink environment [1]. Each subsystem can be considered as an object or a module, which allow the object-oriented programming concept. There are many powertrain models available in the literature. Cho and Hendrick [2] developed a dynamic model of an automotive powertrain system equipped with a six-cylinder petrol engine and a four-speed automatic transmission by using eight states and two time-delays. Kim *et al.* [3] developed a PC-based simulation tool for automotive powertrain systems in MATLAB/Simulink environment. Hendricks [4] developed a new modified mean value engine model and pointed out the differences between this and those developed elsewhere. Hong et al. [5] presented a computer simulation model for evaluating the dynamic behaviour of powertrain systems and control performance for various control laws. Deur *et al.* [6] presented a survey of recent research results of the authors in the field of modeling of automotive powertrain systems and components. Dennis Assanis et al. [7] developed an integrated vehicle system simulation model comprising models for comprehensive transient multi-cylinder engine, torque converter, transmission, transfer case and differentials. Datta Godbole and Sinan Karahan [8] developed a detailed model of the longitudinal dynamics of a typical automobile. But in all these models, the drivetrain was developed as a part of the powertrain which was specific to a particular kind of vehicle and hence cannot be used for any other vehicle. In this work, more focus is given on the development of drivetrain based on the geometry and dynamics of various components of the powertrain and hence can be modified to predict the performance of any vehicle.

Drivetrain

The drivetrain (Fig.1) of a motor vehicle is the group of components that deliver power to the driving wheels. This excludes the engine or motor that generates the power. In contrast, the powertrain is considered to include both the engine or motor and the drivetrain. It is the mechanism by which the power is transferred from the transmission to the vehicle. The transmission gearbox consists of four interconnected planetary gears and clutches to obtain four forward and one reverse speed. The various gear ratios are obtained by fixing various elements of these four planetary gears. The transmission output torque is multiplied by the final drive unit (a single planetary gear) which is on both left and right sides. Finally the torque is transmitted to the left and right drive sprockets. The function of the drivetrain is to couple the engine that produces the power to the driving wheels that uses this mechanical power to rotate the axle.

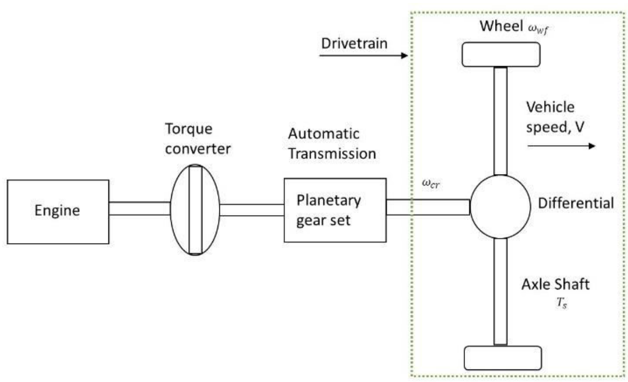

Fig.1 Drivetrain of a front wheel drive vehicle

Modeling of Drivetrain

A drivetrain model is developed using three states in the continuous time domain that includes the stiffness of axle shafts, the wheel inertias, the slip of rubber tyres, and the longitudinal inertia of the vehicle. The three states of the model are

- Axle shaft torque
- Angular velocity of the front wheel and
- Vehicle speed.

The angular velocity of the final drive output shaft is the input to the axle shafts. The axle shaft is modeled as a lumped-parameter torsional spring

$$\dot{T}_s = K_s(R_d\omega_{cr} - \omega_{wf}) \quad (1)$$

where

T_s - the sum of right and left axle torques,
ω_{cr} – angular velocity of the reaction carrier of the planetary gear
ω_{wf} - angular velocity of front-wheel and
K_s - the sum of right and left axle stiffnesses.
R_d – final drive speed reduction ratio

From the rotational dynamics of the driving front-wheel:

$$I_{wf}\dot{\omega}_{wf} = T_s - h_f F_{tf} - T_{rf} - T_{bf} (2)$$

where

h_f- static ground-to-axle height of front wheel
I_{wf} - Front wheel inertia (right and left sides combined)
F_{tf} - Tractive/braking force of front tyre
T_{rf} - Front tyre rolling resistance (right and left sides combined)
T_{bf} – Front wheel brake torque

The tyre rolling resistance torque is obtained by the following formula:

$$T_{rf} = f_r h_f M g$$

$$T_{rr} = f_r h_r M g$$

where

M – vehicle mass
g - Acceleration due to gravity = 9.81 m/s^2
T_{rr} - Rear tyre rolling resistance (right and left sides combined)
f_r – coefficient of rolling resistance (both sides combined)

The tractive/braking force represents the force obtained from the ground. This depends on the tyre slip. The tyre slip comprises the elastic deformation of the treads in the leading edge and the plastic deformation of the trailing edge.

From the longitudinal dynamics of the vehicle:

$$M\dot{V} = F_{tf} - F_{tr} - F_a - F_g \quad (3)$$

where

V – velocity of the vehicle
F_{tr} - Tractive/braking force of rear tyre
F_a - Aerodynamic drag
F_g - Grade resistance = $Mg\sin\theta$
θ - Grade angle

Since the inertia of the driven rear wheel is very small compared with the vehicle mass, its dynamics can be neglected. Thus, the drivetrain model has three states (T_s, ω_{wf} and V) with the three equations (1, 2 and 3). The model is developed by using these three equations in MATLAB/Simulink and it can readily be integrated into the engine and transmission models to get the entire powertrain model. The screenshot of the developed Simulink model is shown in Fig.2

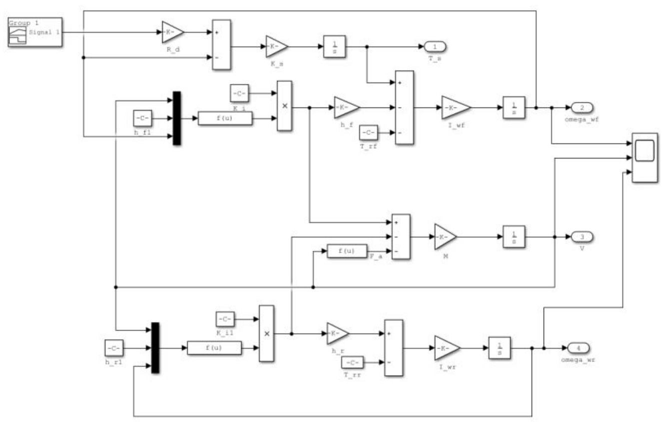

Fig.2 Screenshot of the drivetrain model in MATLAB/Simulink

Results and Discussions

Simulations were carried out in virtual environment with the developed model of the drivetrain to predict the performance under various conditions. The input to the drivetrain model is obtained from the transmission model which in turn gets input from engine model. The engine is simulated under various input conditions such as throttle opening angle in percentage. The results obtained from the engine model is shown in the Fig.3, which shows that there is an automatic upshift of gear from 1 to 2 between 10 and 12 seconds. The gear shifting is based on the percentage of throttle opening and vehicle speed.

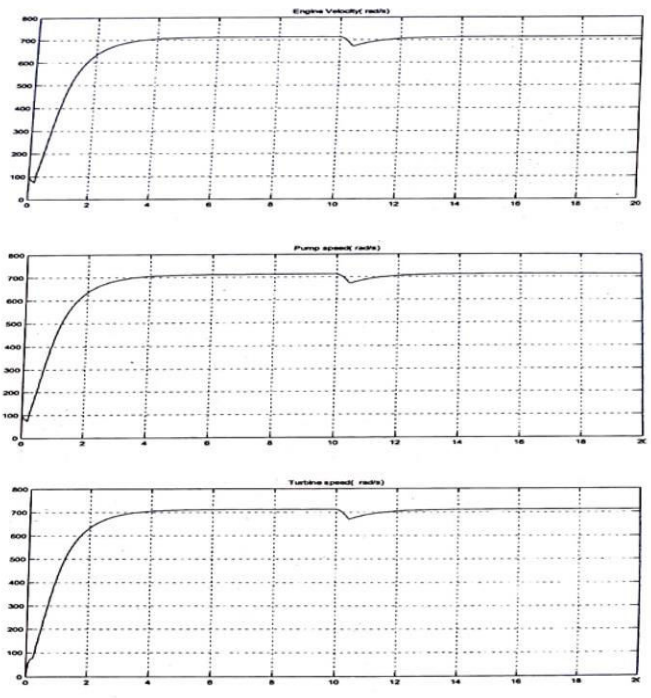

Fig.3 Simulation results from engine and transmission model which is given as input to the drivetrain model

The following plots show the results obtained from the simulation of the developed drivetrain model in MATLAB/Simulink. The first plot (Fig.4) shows the response of the drivetrain model to a ramp kind of input to the reaction carrier speed of the planetary gear of the automatic transmission. The second plot (Fig.5) shows the response to the stepped ramp input for the speed of reaction carrier. The units for the reaction carrier speed, front and rear wheel are rad/s; for the axle shaft torque it is Nm and for the vehicle speed it is in m/s.

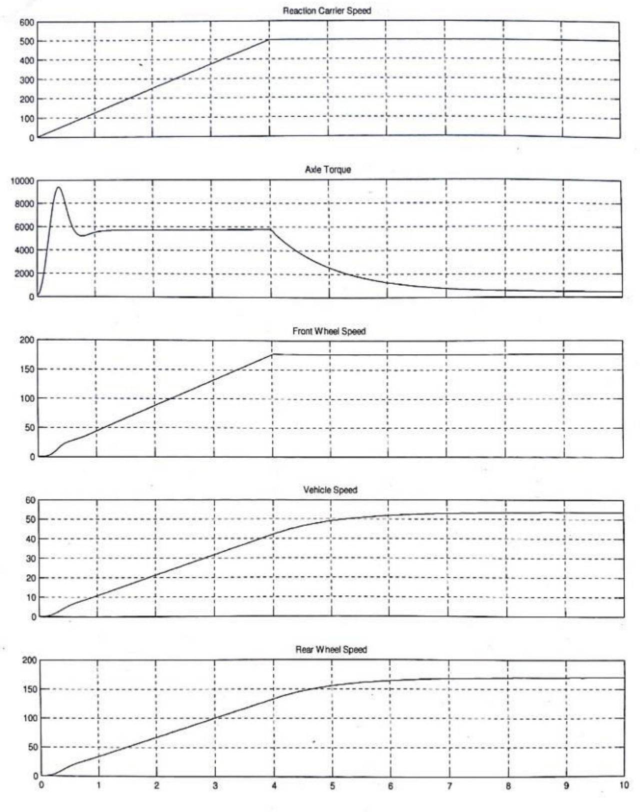

Fig.4 Simulation results for ramp input of reaction carrier

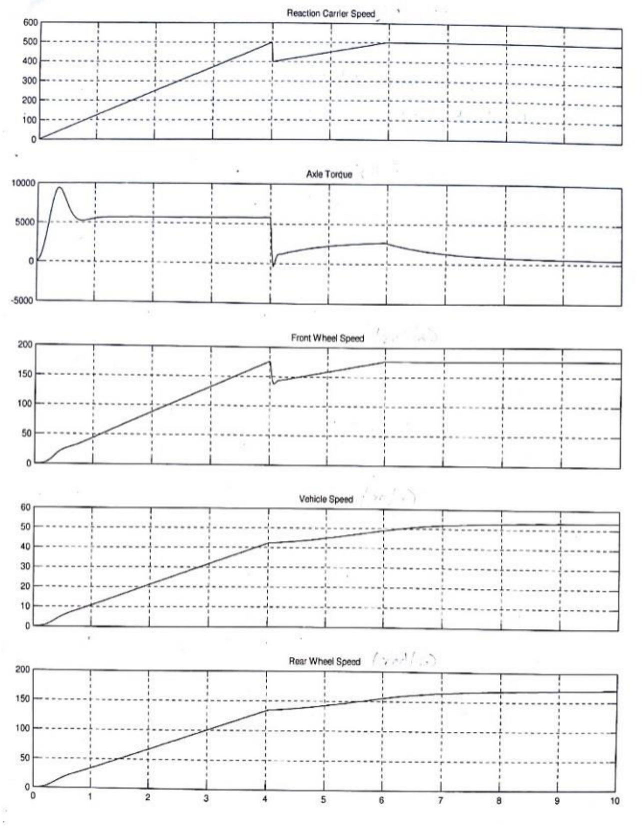

Fig.5 Simulation results for stepped ramp input of reaction carrier

Summary

A simulation model of the drivetrain is modeled as an object-oriented model in MATLAB/Simulink for evaluating the performance. The model describes the dynamics in continuous time domain by using three states:

1. Axle shaft torque dynamics
2. Driving wheel dynamics
3. Vehicle longitudinal dynamics

The model can be easily extended to a larger simulation model for the whole vehicle. The integration of this model with the other components of powertrain is very easy as the model is developed using object-oriented programming concept. The development cost and time can be significantly reduced through the use of simulation based model. Furthermore different transient conditions can be tested on the computer instead of the real test of the hardware. The object-oriented programming concept improves the utility of the developed model by allowing the change of a module in the powertrain.

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BIOGRAPHIES

B. Janarthanan was born Tamilnadu, India in 1971. He received the B.E. degree in Mechanical Engineering from University of Madras in 1992 and the M.Tech and Ph.D degree from IIT Madras in 2001 and 2012 respectively. He is currently a professor in Mechanical Engineering at Mohamed Sathak AJ College of Engineering, Chennai, India. His research interests include vehicle dynamics and vibrations, multibody dynamics and finite element analysis.