Comparative Analysis of Parametric Engine Model and Engine Map Model

ZEESHAN MEMON*, SADIQ ALI SHAH**, AND MUHAMMAD SALEH JUMANI***

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ABSTRACT

Two different engine models, parametric engine model and engine map model are employed to analyze the dynamics of an engine during the gear shifting. The models are analyzed under critical transitional manoeuvres to investigate their appropriateness for vehicle longitudinal dynamics. The simulation results for both models have been compared. The results show the engine map model matches well with the parametric model and can be used for the vehicle longitudinal dynamics model. The proposed approach can be useful for the selection of the appropriate vehicle for the given application.

Key Words: Parametric Model, Engine Map Model, Engine Dynamics.

1. INTRODUCTION

Most of the engine models are related with pollution formation, combustion dynamics, or dynamic control of an engine. Engine is a time-varying and non-linear system whose dynamic is mainly influenced by an induction-to-power delay [1]. One of the first engine models studied was developed by [2]. His model is a combination of first-principle, physical laws, and identification techniques using empirically obtained data for the specific engine. The state equations for the intake manifold are obtained by considering the law of conservation of mass to the intake manifold [3-4]. Rajamani [5] has used the manifold pressure as a state variable by considering the ideal gas equation to relate mass and pressure. The engine rotational dynamics is concerned with the indicated torque, friction torque, and load torque [4,6].

The engine model adopted in this study is an engine dynamics control model. The type of engine model developed is called a mean-value model [4,5,7]. A mean-value engine model is a mathematical/parametric model which is somewhere in the middle of basic transfer function and large cyclic simulation models. It calculates the mean values of the engine states e.g. engine speed and the intake manifold pressure. The engine model is developed as torque-producing device with one inertia where the engine torque is the function of the throttle angle (α), mass flow rate of fuel ($\dot{m}_f$), and the engine speed (ω_e).

An alternate to the parametric model is the engine map (look-up map) which is based on steady-state experimental data and is usually available from the manufacturers [8]. In this study an attempt has been made to construct the engine maps for a second order engine model and a first order engine model respectively using the parametric model. The engine

* Associate Professor, Department of Mechanical Engineering, Mehran University of Engineering & Technology, Jamshoro.
** Associate Professor, Department of Mechanical Engineering, Mehran University of Engineering & Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur.
*** Assistant Professor, Department of Industrial Engineering & Management, Mehran University of Engineering & Technology, Jamshoro.

dynamic model presented in [9,10] is used to compute the intake manifold pressure (p_{man}) and the engine speed (ω_e) and then the engine maps have been constructed using the steady state intake manifold pressure (p_{man}) and the engine speed (ω_e) for the net combustion torque (T_{net}).

In the literature, the engine-map type models are mostly second-order models which consist of two states, p_{man} and ω_e, or first-order models which consist of one state only, ω_e. The second-order system is equivalent to the parametric model.

Fig. 1 shows the block diagram for the three similar engine models with the same throttle input and the engine states as outputs. The difference between the three models is that the parametric model obtains the parametric function, e.g. T_{net}, from the set of parametric equations explained in Section 2 [10], while the engine map models obtain the T_{net} and $\dot{m}_{ao}$ from the engine maps.

The purpose of the comparison of the parametric model and engine map model is to confirm that the engine model is producing the similar results for the engine speed under the same throttle input. The first order engine map model has also been developed and compared with the parametric model to ensure that for the same throttle input, as in parametric model, the engine speed is the same as for the parametric model.

2. PARAMETRIC ENGINE MODEL

In this paper, a spark ignition model of engine consisting of two states and a 5-speed automatic transmission has been used, where the two states are the p_{man} and ω_e [4,9-11].

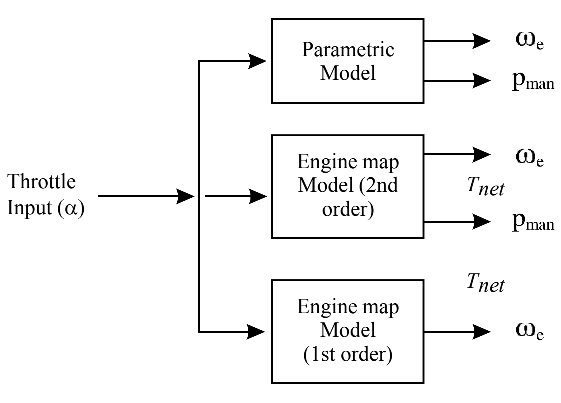

FIG. 1. BLOCK DIAGRAM FOR THREE MODELS

$$\dot{p}_{man} = \frac{RT_{man}}{V_{man}}(\dot{m}_{ai} - \dot{m}_{ao}) \quad (1)$$

$$I_e \dot{\omega}_e = T_i - T_f - T_a - T_p \quad (2)$$

where T_{man} is the manifold temperature, R is the universal gas constant of air, V_{man} is the intake manifold volume, $\dot{m}_{ao}$ and $\dot{m}_{ao}$ characterize flow rate mass into and out of the intake manifold, T_i is the engine combustion torque, T_f is the engine friction torque [4], T_a is the accessory torque, and T_p is the pump torque representing the external load on the engine, and I_e is the effective inertia of engine. The input to the engine model is the throttle angle (α). The reader is referred to [10] for more details on the vehicle dynamic models.

3. SECOND-ORDER ENGINE MAP MODEL

The Equations (3-4) of the 2nd-order engine model are described as follows:

The state Equation (3) for the intake manifold pressure is as follows:

$$\dot{p}_{man} = \frac{RT_{man}}{V_{man}}(\dot{m}_{ai} - \dot{m}_{ao}) \quad (3)$$

All the parametric functions in Equation (3), except $\dot{m}_{ao}(\omega_e, p_{man})$, have been computed using the parametric equations described in Section 2. T_{net} (ω_e,p_{man}) and $\dot{m}_{ao}(\omega_e, p_{man})$ are obtained from the engine map. The state equation for the engine rotational dynamics is as follows:

$$I_e \dot{\omega}_e = T_{net} - T_{load} \quad (4)$$

where, T_{net} (ω_e,p_{man}) is obtained after the losses from the engine map constructed in Fig. 2. T_{load} is the load torque from the torque converter and represents the external load on the vehicle.

To draw the engine map for T_{net} (ω_e,p_{man}) the tabular data is required for a pair of engine speed and manifold pressure. The data has been computed using the computer simulation as shown in Table 1 which shows the partial data for p_{man} (10-13.91kPa). For each pair of (ω_e,p_{man}) there is a corresponding value for T_{net} (ω_e,p_{man}). For constructing an engine map such tabular data is essential for the specific type of engine. Every engine has its own engine map based on the (ω_e,p_{man})

pair. Based on Table 1, engine map has been constructed in Fig. 2 for the manifold pressure ranging from 10-100kPa. The engine map drawn in Fig. 2 shows $T_{net}(\omega_e,p_{man})$ as a function of engine speed and the manifold pressure.

It is important to mention here that the proposed engine map models can be used for ACC (Adaptive Cruise Control) systems. These models are necessary to compute the desired throttle input for the following ACC vehicle. Therefore, it is essential to analyze and validate these models against the parametric models.

TABLE 1. TABULAR DATA FOR AN ENGINE MAP FOR T_{net} (ω_e,p_{man})

No.	Angular Speed (ω_e)rad/s	Manifold Pressure, p_{mas} (kPa)			
		10.00	11.30	12.61	13.91
1.	052.0000	-00.3534	02.2863	04.9261	07.5658
2.	080.1053	-02.4261	00.3304	03.0869	05.8434
3.	108.2105	-04.4988	-01.6255	01.2477	04.1210
4.	136.3158	-06.3119	-03.2880	-00.2642	02.7597
5.	164.4211	-08.2114	-05.7915	-02.3716	01.4705
6.	192.5263	-09.2114	-05.7915	-02.3716	01.0484
7.	220.6316	-10.0386	-06.3394	-02.5969	00.3103
8.	248.7368	-11.4113	-07.5041	-03.5969	00.3103
9.	276.8421	-13.3283	-09.2841	-05.2398	-01.1955
10.	304.9474	-15.5185	-11.3727	-07.2270	-03.0813
11.	333.0526	-18.2529	-14.0767	-09.9005	-05.7243
12.	361.1579	-21.1178	-16.9282	-12.7385	-08.5489
13.	389.2632	-24.6306	-20.5121	-16.3935	-12.2750
14.	417.3684	-28.1444	-24.0970	-20.0497	-16.0023
15.	445.4737	-32.4097	-28.5316	-24.6534	-20.7753
16.	473.5789	-36.6750	-32.9661	-29.2571	-25.5482
17.	501.6842	-41.5902	-38.1353	-34.6804	-31.2255
18.	529.7895	-46.6341	-43.4500	-40.2659	-37.0817
19.	557.8947	-51.3657	-48.4117	-45.4576	-42.5053
20.	586.0000	-55.9424	-53.1982	-50.4539	-47.7097

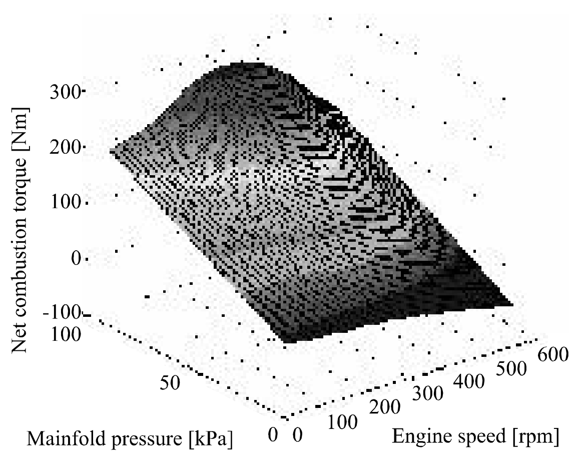

FIG. 2. ENGINE MAP FOR T_{net} AS A FUNCTION OF p_{man} FOR VARIOUS FIXED VALUES OF ω_e

Another analysis, shown in Fig. 3, reveals that for every fixed manifold-pressure p_{man} the magnitude of T_{net} initially increases as a function of engine speed and reaches to a maximum and drops down for higher values of engine speed. The result shown in Fig. 3 has been compared with Figs. 4-9 [5] for the same variables and shows a good agreement with it. Fig. 4 shows the mass outflow rate from the manifold $\dot{m}_{ao}$ (ω_e,p_{man}) as a function of manifold pressure p_{man} for various fixed engine speed ω_e which can be compared with Fig. 5-9 [5]. At lower ω_e, $\dot{m}_{ao}$ is not increasing significantly, while at higher ω_e, $\dot{m}_{ao}$ is increasing as a function of p_{man}.

Fig. 5 shows the control structure for the second order engine map model. The input to the engine map model is the throttle input and the outputs are the engine speed ω_e and the intake manifold pressure p_{man}. At each

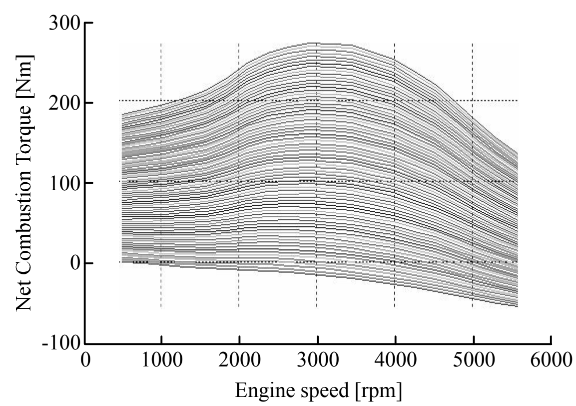

FIG. 3. T_{net} AS A FUNCTION OF ω_e FOR DIFFERENT FIXED MANIFOLD PRESSURE p_{man}

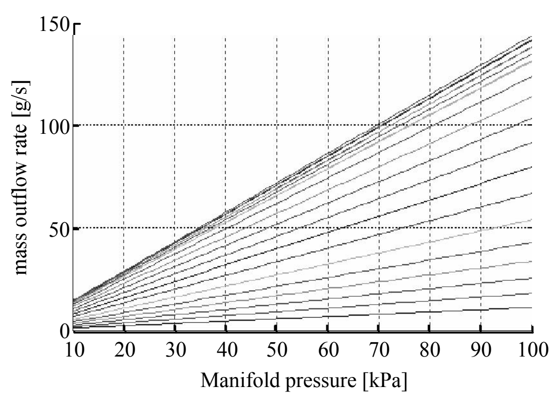

FIG. 4. $\dot{m}_{ao}$ (ω_e,p_{man}) AS A FUNCTION OF p_{man} FOR DIFFERENT FIXED ENGINE SPEEDS ω_e

time step the states are fed back to the engine map to compute the T_{net} for the next step.

4. 1ST ORDER ENGINE MAP MODEL

If filling dynamics of intake manifold are ignored then the second order engine model in Section 3 can be reduced to the first order engine model where the engine dynamics has only one state, the engine speed ω_e [5]. The state equation of the engine dynamics is as follows:

$$I_e \dot{\omega}_e = T_{net} - T_{load} \tag{5}$$

where, T_{net} (α, ω_e) is obtained after the losses from the engine map constructed in Fig. 6. T_{load} is the load torque from the torque converter and represents the external load on the vehicle. T_{net} (α, ω_e) is determined as a steady state function of the throttle angle α and engine speed ω_e.

Figs. 7-10 shows the control structure for the first order engine map model. The input to the engine map model is the throttle angle and the output is the engine speed ω_e. At each time step the state variable is fed back to the engine map to compute the T_{net} for the next step.

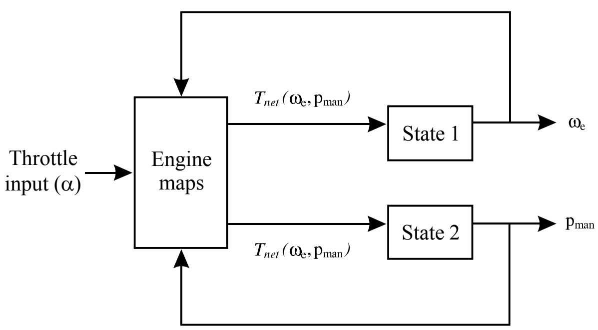

FIG. 5. ENGINE MAP CONTROL STRUCTURE FOR THE SECOND ORDER ENGINE MODEL

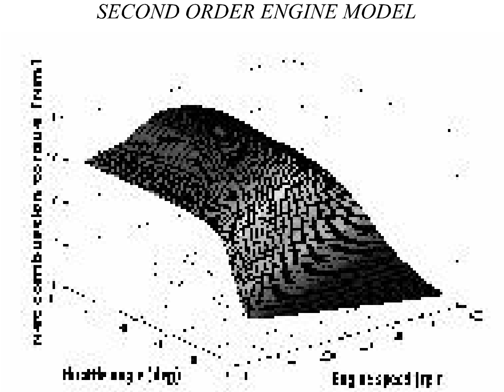

FIG. 6. ENGINE MAP FOR T_{net} AS A FUNCTION OF α FOR VARIOUS FIXED VALUES OF ω_e

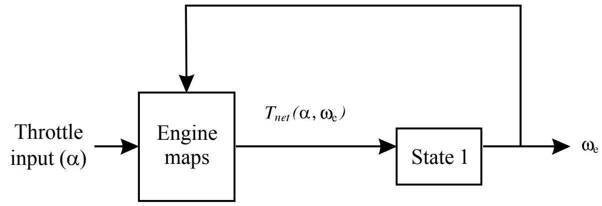

FIG. 7. ENGINE MAP CONTROL STRUCTURE FOR FIRST ORDER ENGINE MODEL

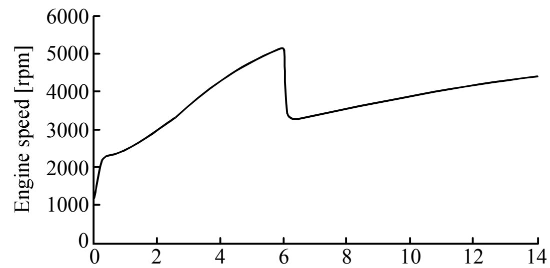

FIG. 8. ENGINE SPEED DURING 1-2 GEAR UP-SHIFT FOR THREE MODELS

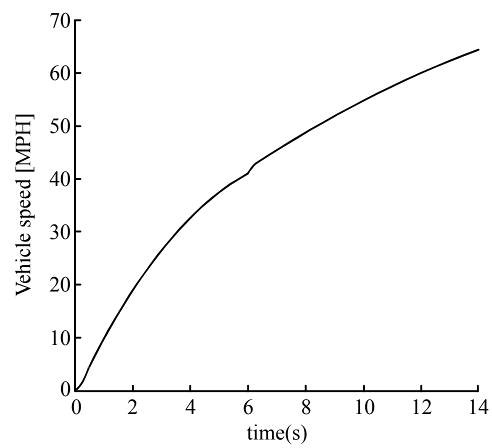

FIG. 9. VEHICLE SPEED DURING 1-2 GEAR UP-SHIFT FOR THREE MODELS

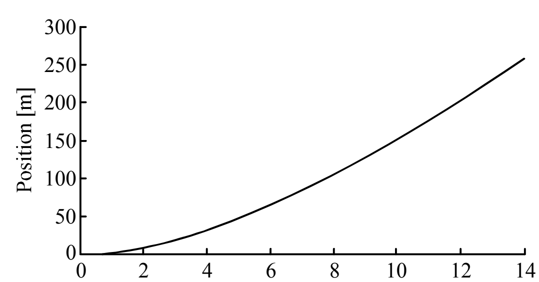

FIG. 10 VEHICLE DISPLACEMENTS DURING 1-2 GEAR UP-SHIFT FOR THREE MODELS

5. CONCLUSIONS

The simulation results are for engine speed, vehicle longitudinal speed and vehicle displacement respectively. Each figure shows the comparison of parametric engine model and the two engine models based on engine maps for 1-2 gear up-shifts. The comparison show that all the three models agree well (overlapping) with each other and that verifies that the engine maps constructed are producing the satisfactory results.

The engine map model has been validated with the parametric engine model. The control input to all models is the same throttle input. The validation has been performed for different throttle inputs and the transient and the steady-state behaviours have been compared.

Since the engine map models have been validated with the parametric model, therefore, these models can be recommended for the adaptive cruise control systems for the following vehicle. The same models have already been used.

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