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An objective analysis of drivability for two wheeler powertrain with control oriented dynamic model ⋆

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Abstract: The objective of this work is to estimate drivability characteristics parameters of two wheeler powertrain with control oriented powertrain model. The evaluation is essential for defining drivability characteristics for a future electric variable transmission (EVT) powertrain. The mathematical model for the complete powertrain is developed using suitable modeling approaches for the different sub-modules of the complete system. The Spark Ignition (SI) engine model used for this work is developed from mean value model approach and experimentally validated with test data from TVS Motor Company, India. The model is integrated with two types of transmission models, Continuous Variable Transmission (CVT) and Manual Transmission (MT). It simulates dynamic power-flow from the engine to wheel for analyzing longitudinal drivability of the vehicle for both powertrain configurations. It is proposed that the drivability can be measured with certain parameters which show good correlation with subjective assessments for vehicle launch as well as tip in condition. The objective assessment of both types of powertrains is performed using the above mentioned powertrain models. The results of the simulation for drivability tests are discussed in this paper.

Keywords: Drivability, Powertrain, Control oriented model, Manual transmission, Continuous variable transmission, Launch, Tip in

1. INTRODUCTION

India, which is one of the leading developing countries, witnesses an annual growth of 11% in vehicle sales Posada et al. (2011). According to ICCT report (with data from World Road Statistics WRS, 2010) Posada et al. (2011), two wheeled vehicles comprise 80% of the total vehicle sales in India. The gear-less two wheeler, which is a major portion of the total two wheeler vehicles has witnessed a growth of 31% (SIAM industry performance report for 2013-2014) Ray (2014). This is the strongest growth among the different categories of two wheelers. Unfortunately the current powertrain configuration of gear-less vehicles is not fuel efficient and it is necessary to investigate about increasing its efficiency. A conventional powertrain of a gear-less two wheeled vehicle consists of an internal combustion (IC) engine, a centrifugal clutch system and a rubber-belt driven CVT. The advantages of the system are the smooth drivability due to the powertrain topology and the ability to operate the IC engine in better operating zone. The main disadvantage of the system is the lower system level efficiency due to high frictional losses in the rubber belt of the CVT. The high frictional loss of the CVT system nullifies the advantage of operating the IC engine in the suitable operating zone. On the other hand, the MT consists of a friction clutch system with step geared powertrain for transferring the engine power to the wheel. It has the advantage of low loss of the transmission. However the system lacks of drivability for transient city driving conditions.

The main intention of this work is to perform an objective evaluation of drivability between gear-less transmission (CVT) and geared transmission (MT) for a small powered powertrain, with a control oriented dynamic model. The control oriented model for the IC engine is developed from first principles, based on a production engine and verified with the test data available from TVS Motor Company, India. The IC engine model is coupled with two different models for CVT and MT powertrain. Both the powertrain models are simulated for vehicle launch and tip in scenarios. The important parameters which can characterize drivability, are captured from the simulated test for objective evaluation. The model developed during this work will be used in further work for optimal control development of an integrated powertrain unit with Electric variable transmission (EVT). The engine platform for the research is a 110 cc SI engine with carburettor fuel metering from TVS Motor Company. The detailed technical specifications of the engine could not be provided in this paper due to confidentiality restrictions.

The remaining part of the paper is structured as follows: Section 2 describes the SI engine model, Section 3 de-

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scribes the CVT and MT models, Section 4 discusses the drivability characteristics of two wheelers and Section 5 discusses the simulation results.

2. TORQUE GENERATION MODEL OF SPARK IGNITION ENGINE

Significant works have already been carried out on mathematical model development of Spark Ignition (SI) engine. Guzzella and H.Onder (2001) explained the mean value modeling and discrete event modeling for a SI engine. The mean value approach considers all the parameters of the model as functions of time, while the discrete event based model considers parameters as function of crank angle position. Heywood (2001), Kiencke and Nielsen (2001) explained different thermodynamic cycles for an IC engine. Heywood (2001) & Guzzella and H.Onder (2001) & Kiencke and Nielsen (2001) discussed the inlet manifold dynamics for an IC Engine. Heywood (2001); Sendyka and Filipczyk (1995) & Sendyka and Filipczyk (1995) described different characteristics of carburetor air flow and fuel flow models. Alla (2002) & Chan and Zhu (2001) & Kakaee et al. (2011) discussed the effect of ignition timing on the combustion process.

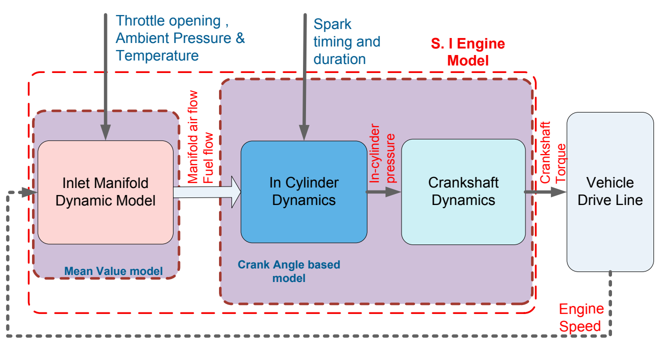

Fig. 1. Implementation of Spark Ignition Engine model

The IC engine is an energy converter which converts chemical energy to mechanical energy. In this work, a four-stroke SI engine is considered as the main energy source of the vehicle. A carburetor controls the fuel flow for the SI engine. Although fuel injection technology is becoming the norm in bigger capacity engines, in smaller displacement engines (less than 150 cc) fuel metering is controlled by carburetor. The proposed model has been described in detail in Das et al. (2015) and a summary is given here. It is a hybrid model which consists of mean value as well as discrete event modeling parts. Fig. 1 shows the interaction of both types of models. The inlet manifold dynamics is slower than the combustion dynamics inside the combustion chamber. The inlet manifold model is implemented as mean value model and in cylinder dynamics is modeled as discrete event model. The overall engine model is structured with three sub models as shown in Fig. 1.

- Inlet manifold model
- In-cylinder dynamics
- Crankshaft dynamics

The "Inlet manifold model" calculates manifold air flow (MAF), fuel flow (FF), manifold air pressure (MAP) and air fuel ratio (AFR). The value of MAF and FF are used in the "In-cylinder dynamics" model. The "In-cylinder dynamics" model calculates in-cylinder pressure for the "Crankshaft dynamics" model. The dynamic torque generated by the crankshaft can be expressed as

$$J(\alpha)\dot{\omega}_e = (p(\alpha) - p_{atm})A_p \frac{ds(\alpha)}{d\alpha} - m_{oscillating}\frac{ds(\alpha)}{d\alpha}\frac{d^2s(\alpha)}{d\alpha^2}\omega_e^2 - \mathbf{T}_{clutch} - \mathbf{T}_{frictional} \quad (1)$$

where ω_e is engine speed, α is crank angle, p is in-cylinder pressure, p_{atm} is atmospheric pressure, A_p is the surface area of the piston, s is the stroke of the engine, $m_{oscillating}$ is the oscillating mass of the the crankshaft, piston and connecting rod assembly , $\mathbf{T}_{clutch}$ is the friction torque of the clutch and $\mathbf{T}_{frictional}$ is a torque corresponding to the engine frictional losses. $J(\alpha)$ is the moment of inertia of the crankshaft, piston and connecting rod assembly and is given by

$$J(\alpha) = \left(m_{rotational}r^2 + m_{oscillating}\left(\frac{ds(\alpha)}{d\alpha}\right)^2 \right) \quad (2)$$

where $m_{rotational}$ is the rotating mass of the the crankshaft, piston and connecting rod assembly and r is the crankshaft radius. The combined model of the SI engine is verified

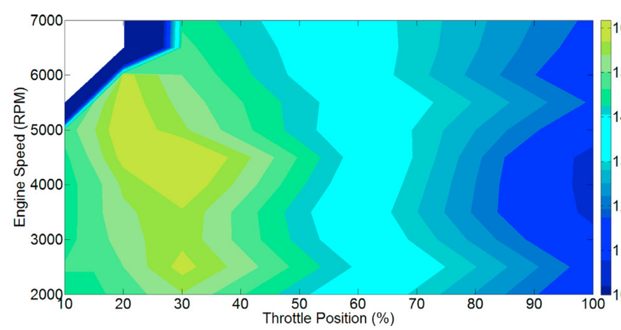

Fig. 2. Target AFR for full operating zone of the SI engine (derived and proposed by TVS Motor Company)

with experimental results for the full operating zone of the engine. The model is calibrated to achieve the target air fuel ratio. The target air fuel ratio for the full engine operating zone is shown in Fig. 2 which is experimentally derived and utilized by TVS Motor Company for a 110 cc SI engine. The values of AFR are influenced by the target vehicle driving characteristics, target fuel consumption and prevention of over heating of the engine. The AFR is maintained richer (AFR < 14.6) with higher throttle value to reduce the cylinder head temperature by the cooling effect of fuel.

Fig. 3 shows the comparison of simulation results and actual values of mean crankshaft torque for the full operating zone of the SI engine. The model shows significant errors in two zones.

- Low speed and high throttle operating region.
- Low throttle and high speed operating region.

The 1st zone is not a stable zone of operation for experimentation and the experimental results are prone to error due to the same reason. Although the model can be further tuned to reduce the errors, it is justified to use this