2022-01-0665 Published 29 Mar 2022

Model Based Evaluation of Parallel Hybrid Concepts for a Scooter for Reduced Fuel Consumption and Emissions

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Citation: Mathivanan, A., Elango, P., Kakani, R., Das, H.B. et al., "Model Based Evaluation of Parallel Hybrid Concepts for a Scooter for Reduced Fuel Consumption and Emissions," SAE Technical Paper 2022-01-0665, 2022, doi:10.4271/2022-01-0665.

Received: 24 Jan 2022 Revised: 24 Jan 2022 Accepted: 11 Jan 2022

Abstract

Hybrid drive trains have to be cost effective for implementation in small two-wheelers especially scooters which constitute the majority of the market in several Asian countries. Integrating an electric motor with the conventional IC Engine drivetrain while retaining the CVT (Continuously Variable Transmission) is a cost-effective proposition. Such a development will need accounting for the behaviour of the engine, electrical drive and the belt driven CVT. A map-based engine model and a physics-based CVT model were developed in Simulink and validated with experimental data on the WMTC drive-cycle. A steady state map-based emission model and a motor model were also used. Simulations were performed on two parallel hybrid layouts namely P2 wherein the electric motor was placed before the CVT and P3 where the motor was placed in the final drive after the CVT while retaining the base 110 cc scooter powertrain. Both P2 and P3 hybrid layouts consumed 38 and 47% lesser fuel respectively and also emitted lesser HC and CO emissions than the conventional powertrain. The losses in the CVT were higher with P2 hybrid layout. Additionally, the P3 hybrid powertrain will be easier to implement on an existing vehicle as the motor is placed after the CVT and is more preferable. Though the NO_x emission with the hybrid layouts was higher since the engine operated in the more efficient zones it can be curtailed by restricting the maximum operating torque with a small penalty in fuel economy.

Introduction

Hybrid drives have been a successful solution for improving powertrain efficiency through the addition of an electric drive alongside the Internal Combustion Engine (ICE) [1]. The electric drive is used to assist the ICE facilitating the operation of the ICE in its most efficient zone there by reducing the fuel consumption and emissions [2]. Moreover, electric drives also present advantages such as energy recuperation through regenerative braking, highly efficient operation at low speeds and instantaneous torque delivery which are highly desirable for city driving conditions with frequent start/stops where the conventional ICE drives tend to be inefficient.

The introduction of electric drive components like (electric) motor, battery, transmission and power-transfer mechanism between the ICE and motor pose new and complex design and control requirements which generally make the hybrid drive more expensive than its conventional counterpart [3]. This is certainly of concern while implementing a hybrid drive on low-cost personal transport vehicles such as scooters which constitute a major share of the market in several Asian countries. In India, two-wheelers constitute about 80% of the market share [4]. While looking at alternatives for such small vehicles often the need will be to make minimal changes and retain as many of the existing components as possible. Thus, cost effective and easy to implement approaches will be required which is a challenging task.

Modern ICE based scooters use a CVT (Continuously Variable Transmission) which is better in terms of drivability when compared to manual transmissions. The CVT is generally encased with the ICE as a single unit. Replacing these might require redesigning the whole unit which is time consuming and costly. A simpler solution would be to integrate the electric drive components on to the existing powertrain while retaining the base ICE and CVT unit. Even in this case, different hybrid layouts based on the placement of motor either before or after the CVT are possible. The performance of the powertrains will be greatly influenced by the layout that is chosen. Thus, before actual implementation a detailed simulation using proper models under standard driving conditions will help identify the most suitable design. It will also allow the sizing of the components like the battery

- Compared to the base conventional powertrain, both hybrid layout showed significant reduction in HC emissions while CO emissions were nearly the same when using a map-based emission model obtained from steady state experiments.
- The NO_x emissions of the P2 hybrid layout was 164% higher and P3 hybrid layout was 46% higher than the base powertrain. This was due to the operation of the ICE in the high torque regions where it is more efficient. However, these can be reduced by restricting the maximum torque of the ICE.
- The operation of ICE in the P2 hybrid layout has lesser transients compared to the P3 hybrid layout.

On the whole, P3 hybrid powertrain was better in terms of fuel consumption and emissions compared to P2 hybrid powertrain. Also, P3 hybrid powertrain will be easier to implement on an existing vehicle without packaging constraints as the motor is placed after the CVT. Though the P3 layout is preferable it might have an effect on the drivability as it increases the un-sprung mass. A cost function minimizing the efficiency, NO_x, HC and CO can be used to find the optimised operating point of the ICE under the P3 mode for further improving the overall performance.

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Acknowledgements

The authors thank the Indo-German Science and Technology Centre, Delhi for funding this work. The authors also thank M/s TVS Motor Company for the technical and in kind support for this work. We would like to thank our technical staffs Muthukumaravel S, Lokesh A, Aashif Ali M and Thirumoorthy R for their support.

ISSN 0148-7191