2022-01-0665 Published 29 Mar 2022

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

Arulkumaran Mathivanan, Pradeev Elango, and Raghav Kakani IIT Madras

Himadri B Das TVS Motor Co., Ltd.

A Ramesh IIT Madras

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.

References

1. Zhu, D., Pritchard, E., Dadam, S.R., Kumar, V. et al., "Optimization of Rule-based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming," *Combustion Engines* 184, no. 1 (2021): 3-10, doi:10.19206/CE-131967.
2. Dadam, S.R., Jentz, R., Lenzen, T., and Meissner, H., "Diagnostic Evaluation of Exhaust Gas Recirculation (EGR) System on Gasoline Electric Hybrid Vehicle," SAE Technical Paper 2020-01-0902 (2020). https://doi.org/10.4271/2020-01-0902.
3. Ramachandra, P., Halahali, M., and Anantha, P., "Technology Evaluation for Two Wheeler Based Personal Mobility in Emerging Markets beyond 2020," SAE Technical Paper 2016-32-0074 (2016). https://doi.org/10.4271/2016-32-0074.
4. Lueckenbach, S., Moser, U., Haake, B., and Frank, J., "On-Board Diagnostic Related Challenges on Two-Wheelers Related to the Upcoming Bharat Stage VI Emission Standards," SAE Technical Paper 2017-26-0147 (2017). https://doi.org/10.4271/2017-26-0147.
5. Kapadia, J., Kok, D., Jennings, M., Kuang, M. et al., "Powersplit or Parallel—Selecting the Right Hybrid Architecture," *SAE Int. J. Alt. Power* 6, no. 1 (2017), doi:10.4271/2017-01-1154.
6. Viorel, I.-A., Szabo, L., Löwenstein, L., Şteţ, C., (2004). "Integrated Starter-Generators for Automotive Applications," 45.
7. Melaika, M., Mamikoglu, S., and Dahlander, P., "48V Mild-Hybrid Architecture Types, Fuels and Power Levels Needed to Achieve 75g CO2/km," SAE Technical Paper 2019-01-0366 (2019). https://doi.org/10.4271/2019-01-0366.
8. Zhu, C., Liu, H., Tian, J., Xiao, Q. et al., "Experimental Investigation on the Efficiency of the Pulley-Drive CVT," *International Journal of Automotive Technology* 11, no. 2 (2010): 257-261, doi:10.1007/S12239−010−0032−2.
9. Adyanthaya, V., Joshi, N., and Samant, A., "Optimization and Evaluation of a Belt Driven CVT for a 125 cc, 4 Stroke Scooter," SAE Technical Paper 951773 (1995). https://doi.org/10.4271/951773.
10. Chen, T.F., Lee, D.W., Sung, C.K., "An Experimental Study on Transmission Efficiency of a Rubber V-belt CVT", *Mechanism and Machine Theory*, 33, 4, 1998, 351-363, ISSN 0094-114X, doi:10.1016/S0094-114X(97)00049-9.
11. Ehsani, M., Gao, Y., Gay, S., Emadi, A., (2004). "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design," doi:10.1201/9781420037739.
12. Chen, H., Li, L., and Küçükay, F., "Study of Series-Parallel and Power-Split DHT for Hybrid Powertrains," *Automot. Innov.* 4 (2021): 23-33, doi:10.1007/s42154-020-00126-w.
13. Lanzarotto, D., Marchesoni, M., Passalacqua, M., Pini Prato, A. et al., "Overview of Different Hybrid Vehicle Architectures," *IFAC- PapersOnLine* 51, no. 9 (2018): 218-222, doi:10.1016/j.ifacol.2018.07.036.
14. Gao, Y. and Ehsani, M., "A Mild Hybrid Drive Train for 42 V Automotive Power System-Design, Control and Simulation," SAE Technical Paper 2002-01-1082 (2002). https://doi.org/10.4271/2002-01-1082.
15. Hosoi, Y., "Improvement of Fuel Consumption for the Strong Hybrid Motorcycle," *SAE Int. J. Fuels Lubr* 5, no. 2 (2012).
16. Schacht H.-J., Roland, K., Franz, W., and Schmidt Stephan, P., "Concept Study of Range Extender Applications in Electric Scooters," *JSAE 20119592/SAE 2011-32-0592.*
17. Amjad, S., Rudramoorthy, R., Neelakrishnan, S., and Varman, K., "Modeling and Simulation of Plug-In Hybrid Electric Two Wheeler for All-Electric Range Requirements," SAE Technical Paper 2011-28-0002 (2011). https://doi.org/10.4271/2011-28-0002.
18. Gopi Krishnan, N. and Wani, K., "Design and Development of a Hybrid Electric Two-Wheeler," SAE Technical Paper 2015-26-0118 (2015). https://doi.org/10.4271/2015-26-0118.
19. Ceraolo, M., Caleo, A., Capozzella, P., Marcacci, M. et al., "Operation and Performance of a Small Scooter with a Parallel-Hybrid Drive-Train," SAE Technical Paper 2004-32-0077 (2004). https://doi.org/10.4271/2004-32-0077.
20. European Commission, "Directive 2002/51/EC of the European Parliament and of the Council of 19 July 2002 on the Reduction of the Level of Pollutant Emissions from Two- and Three-Wheel Motor Vehicles and Amending," *Official Journal of the European Communities, OJ* L226 (2002).
21. Zardini, A., Clairotte, M., Lanappe, G., Giechaskiel et al., "Preparatory Work for the Environmental Effect Study on the Euro 5 Step of L-Category Vehicles," (2016), doi:10.2790/777240.
22. Kumar, V., Zhu, D., and Dadam, S., "Intelligent Auxiliary Battery Control—A Connected Approach," SAE Technical

Paper 2021-01-1248 (2021). https://doi.org/10.4271/2021-01-1248.

23. Goerke, D., Bargende, M., Keller, U., Ruzicka, N. et al., "Optimal Control based Calibration of Rule-based Energy Management for Parallel Hybrid Electric Vehicles," *SAE Int. J. Alt. Power.* 4(1):2015, doi:10.4271/2015-01-1220.
24. Kim, K. and Kim, H., "Axial Forces of a V-Belt CVT," *KSME J.* 3 (1989): 56-61, doi:10.1007/BF02945685.
25. Zeraoulia, M., Benbouzid, M., Diallo, D., "Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study," *IEEE VPPC'05*, Sep 2005, Chicago, United States. 280-287. ffhal-00533362f
26. Zhu, D., Pritchard, E.G.D., and Silverberg, L.M., "A New System Development Framework Driven by a Model-Based Testing Approach Bridged by Information Flow," *IEEE Systems Journal* 12, no. 3 (2016): 2917-2924, doi:10.1109/JSYST.2016.2631142.
27. Garg, M., Deshpande, G., Gohl, J., and Sundaresan, S., "Development and Application of Control-Oriented Power Train Model for a Variomatic Scooter," SAE Technical Paper 2007-32-0097 (2007).
28. Filipi, Z., Fathy, H., Hagena, J., Knafl, A. et al. "Engine-in-the-Loop Testing for Evaluating Hybrid Propulsion Concepts and Transient Emissions - HMMWV Case Study," *SAE Transactions* 115 (2006): 23-41. http://www.jstor.org/stable/44681888.

Contact Information

Ing. ArulKumaran Mathivanan
Department of Mechanical Engineering, Indian Institute of Technology Madras
arulkumaran3005@gmail.com

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.