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Design and Optimization of a P4 mHEV Powertrain

Vance Hudson, Matthew Hancock, Moinul Shahidul Haque, Amine Taoudi, and Randolph Follett
Mississippi State University

Andrea Strzelec University of Wisconsin

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Abstract

The EcoCAR Mobility Challenge (EMC) is the latest edition of the Advanced Vehicle Technology Competition (AVTC) series sponsored by the US Department of Energy. This competition challenges 11 North American universities to redesign a stock 2019 Chevrolet Blazer into an energy-efficient, SAE level 2-autonomous mild hybrid electric vehicle (mHEV) for use in the Mobility as a Service (MaaS) market.

The Mississippi State University (MSU) team designed a P4 electric powertrain with an 85kW (113.99 HP) permanent magnet synchronous machine (PMSM) powered by a custom 5.4 kWh lithium-ion energy storage system. To maximize energy efficiency, Model Based Design concepts were leveraged to optimize the overall gear ratio for the P4 system. To accommodate this optimized ratio in the stock vehicle, a custom offset gearbox was designed that links the PMSM to the rear drive module. This gearbox is a three-gear train with a ratio of 3.143:1, comprised of helical gears with integrated shafts within a custom two-piece aluminum case. Moreover, the rear drive module was modified to ease the integration process of the designed gear in the vehicle in compliance with competition rules. Overall, the designed P4 system contributes to a 34% improvement in fuel economy over the stock vehicle on the EMC combined drive cycle.

Introduction

The EcoCAR Mobility Challenge [1] (EMC) is billed as North America's premier collegiate engineering competition, headline sponsored by the United States Department of Energy (DOE), the MathWorks, and General Motors (GM) and managed by Argonne National Lab (ANL). This 4-year competition challenges eleven North American universities to redesign a 2019 Chevrolet Blazer to integrate advanced hybrid powertrains and Society of Automotive Engineers (SAE) Level 2 Autonomy. In year one of the competition, the Mississippi State University (MSU) team analyzed the competition requirements and selected a parallel through-the-road P4 mild hybrid electric vehicle (mHEV) architecture. The selected architecture consists of a GM LTG 2.0 L I4 turbocharged engine coupled to a GM 9T50 M3D nine speed transmission driving the front wheels. The engine is fueled by a custom 45.39 kg (100 lb) fuel tank located under the vehicle. The electric (or P4) powertrain is powered by a custom Hybrid Design Services (HDS) 5.4 kWh energy storage system (ESS) connected to a Cascadia Motion PM150DX inverter and an 85 kW (113.99 hp) HVH SS-250-090 motor. As the vehicle does not have an electric-only mode, it remains a mild hybrid despite the capability of the P4 powertrain.

A survey of the literature indicates a variety of investigations of powertrain design for a parallel hybrid vehicle design. In particular, Karaoglan, et. al [2] explored the impact of gear ratio changes in a parallel hybrid system where the internal combustion engine (ICE) and electric machine (EM) were connected through a torque coupling unit with a single output passing through a gearbox and differential to the wheels of the vehicle. Additionally, Hofstetter, et. al [3] explored design optimization of a gearbox for an e-axle while considering the packaging restrictions of the intended installation. Their approach allowed for a holistic review of the specifications needed in the final gearbox rather than forcing late-stage redesigns to account for the intended vehicle installations. Zhu et. al [4] explored the impact of incorporating measurement feedback in optimization of powertrain energy management. Aberšek et. al [5] created an Expert System program to optimize the design of a gearbox, taking into account the interaction of more than one gear pair at once. This provided a more complete optimization of design, accounting for secondary items including bearings and shafts. Oakley [6] described the process of gearbox design and integration in a previous AVTC vehicle at MSU. The series-parallel plug-in hybrid electric vehicle (pHEV) gearbox required integration of three inputs into a single output while facing similar time, budget, and manpower restraints to our project. This work expands on the previous literature through a more detailed exploration of the design process, specifically expanding in the area of the gear and overall gearbox design.

In MSU's design, the through-the-road parallel hybrid architecture separates the engine and motor and does not require a coupling between the two as shown in Figure 1.

vehicle. This ratio was then used to create a 3-gear train that also met the physical requirements of the powertrain before designing a case and mounting structure around it. After manufacturing, the team assembled and installed the system in the vehicle before gradually ramping up testing.

The ramp-in process for bringing the motor up to 100% torque rating is not yet fully finished due to complications from the ongoing COVID pandemic and other priorities for competition testing. The team plans to finish this process in the coming months and ensure the gearbox does not suffer any negative effects from the higher load experienced. As the EMC cycle conclusion is approaching, there is no plan to make any modifications that require new gears or a new case, but the team plans to explore other options for optimization. This includes testing how varying the fluid used and the fluid level in the system affects the efficiencies and temperature, determining the conditions that require the electric fan for the gearbox cooler to be turned on, and tuning the torque ramping for the motor to avoid gear damage while still maximizing torque application.

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