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ELECTRIC, FUEL CELL, AND HYBRID VEHICLE, TRANSMISSION AND DRIVELINE, VEHICLE DYNAMICS AND CONTROL

Physics-Based Modeling of Electro-Hydraulic Actuated Dual-Clutch Transmissions in Hybrid Electric Vehicles (HEVs)

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Abstract

A physics-based model is developed in this paper for control synthesis and design of electrohydraulic actuated dual-clutch transmissions in hybrid electric vehicles (HEVs). With coordinated control of an electric oil pump (EOP) and two proportional solenoid valves, the hydraulic pressures are regulated and the engagement/disengagement of one clutch on the engine side and the other on the motor side allows the HEV powertrain to switch between various driving modes. The engagement and disengagement of each clutch are described by a state diagram including three states: piston moving, clutch slipping, and clutch engaged. Overall, the physics-based model includes a hydraulic system, which describes the interaction among the filling dynamics of the upstream pipeline and two clutch actuation chambers, and a mechanical system, which contains the piston dynamics and rotational dynamics of the dual-clutch transmission. The results show that during switching from EV mode to HEV mode, the pressure in the engine side clutch actuation chamber raises whereas the pressures in both the upstream pipeline and motor side clutch actuation chamber drop during the transient, which if not well controlled may result in slipping of the clutch on the motor side at higher load conditions. Based on the physics-based model, optimal control commands can be obtained for minimum energy loss during acceptable engagement time and sufficient torque delivery at various speed and load conditions. Results also show that by including the piston motion and pressure dynamics while treating the proportional solenoid valves as static systems, the proposed model is able to predict the current-to-pressure hysteresis during the engagement and disengagement of the clutch.

Keywords Hybrid electric vehicle · Dual-clutch transmission · Mode switching control · Hydraulic pressure · Electrohydraulic actuated clutch · Current-to-pressure hysteresis

Abbreviations

HEV	Hybrid electric vehicle
ISG	Integrated starter generator
TM	Traction motor
EOP	Electric oil pump
EV	Electric vehicle
RE	Range extended
ICE	Internal combustion engine
PWM	Pulse width modulation
ATF	Automatic transmission fluid

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1 Introduction

Due to the stringent vehicle emission and fuel economy standards, techniques such as advanced internal combustion engines (ICEs) (Chiang et al., 2022; Karczewski et al., 2021), electric vehicles (EVs) (Qiao et al., 2020) and hybrid electric vehicles (HEVs) (Fu et al., 2021; Martinez et al., 2016; Zeng et al., 2018a, 2018b; Zhao et al., 2022) have been developed. HEVs or plug-in HEVs achieve lower emission and better fuel economy than conventional internal combustion engine vehicles (ICEVs) with more flexibility, longer range, and lower cost than EVs (Dauphin et al., 2023; Fu et al., 2021; Martinez et al., 2016; Zeng et al., 2018a, 2018b). To achieve optimal energy management, a hybrid electric vehicle (HEV) must seamlessly switch between various driving modes, typically facilitated by the engagement and disengagement of clutches (Zeng et al., 2018a, 2018b). The engagement of clutches needs to be properly controlled