Multivariable Control of Gear Shift for a Parallel-type Hybrid Electric Vehicle with Dual Clutch Transmission

Soo Young KIM[1], Sei Bum CHOI[1*]

[1]Department of Mechanical Engineering, KAIST, Daejeon 34141, Korea

westkllr@kaist.ac.kr
[*]sbchoi@kaist.ac.kr

Abstract
This paper describes a multivariable control strategy for gear shifts of a parallel hybrid electric vehicle (HEV) equipped with a dry-type dual clutch transmission (DCT). Unlike conventional vehicles powered only by internal combustion engines, a hybrid electric vehicle can actively utilize the drive motor to improve its gear shifting performances. In addition, a vehicle equipped with DCT requires accurate torque transfer control during gear shifts to ensure good shift quality without smoothing effects from torque converter. In this paper, an integrated torque and speed control strategy is developed to minimize the driveline oscillations that occur during gear shifts and to complete the shift as fast as the driver wants. A robust H-infinity controller is designed to simultaneously control clutch slip speed and transmission output torque, particularly in inertia phase that mostly determines the whole shift quality. The effectiveness of the proposed control strategy is verified through simulations using a valid vehicle model developed in MATLAB/SimDriveline.

Keywords : Hybrid electric vehicle, dual clutch transmission, robust multivariable control, gear shift control

1. Introduction

Dual clutch transmission (DCT) exhibits superior shifting performances over other types of transmissions by using two clutches simultaneously in a gear shift. However, DCTs are more likely to produce shift shock compared with conventional hydraulic automatic transmission since there is no dampening effect from torque converter. Accurate cooperated control of clutches and power sources is required especially for vehicles with DCT to improve the shift smoothness. This paper deals with the gear shift control of a parallel-type hybrid electric vehicle (HEV) with DCT. Because the HEV has a drive motor attached in front of the transmission part, its shift performance can be considerably improved using the fast torque control of the motor. One chronic problem arising in the DCT shift control is the strong coupling effects between the speed and torque control loops. In order to handle such loop interaction effectively, a robust multivariable control using H-infinity loop shaping is proposed in this paper.

2. Gear shift controller

2.1 Shift control strategy

A gear shift process of DCTs is discriminated as torque phase where the torque handover from the off-going clutch to the on-coming one is performed and inertia phase where the speed of the power sources is synchronized with the input shaft speed with a new gear ratio. Since the shift quality is dominantly determined in the inertia phase where the inertial effects of the power sources cause large driveline oscillations, many previous studies focused on the inertia phase control to improve the shifting performances [Kim, 2017]. This research also developed an effective control method for the inertia phase of the HEV with DCT. The speed change of the power sources during the inertia phase produces large overshoot of the output shaft torque, which leads to poor ride quality. The regenerative operation of the drive motor can be used for the inertia torque compensation, which also improves fuel economy. In this paper, an integrated torque and speed control approach is proposed such that the shift control problem is interpreted as the torque and speed tracking problem. Given the reference value trajectories of the slip speed and the output torque satisfying the desired shift performances, an effective controller is required to track them accurately.

2.2 Multivariable controller design

A multivariable controller is designed to track the reference state trajectories taking into account the loop interactions between the speed and torque control loops. The control-oriented model used for the controller design is the third order linear model of the DCT driveline developed in [Kim, 2018]. The control states are the slip speed of the on-coming clutch (clutch 2) and the output shaft torque, and the torque inputs of the drive motor and the on-coming clutch are regarded as control inputs. Next, a robust multivariable controller using H-infinity loop shaping is designed based on the control-oriented model for the gear shift. The design procedure of the controller is two stages: design of the pre-filter to shape the open-loop response of the plant, and robust stabilization of the closed-loop system by solving the H-infinity problem. The detailed design process is specified in [Skogestad, 2007]. Here, the desired loop shape for the pre-filter is determined as a pure integrator with gain crossover frequency of 10rad/s considering the physical characteristics of the actual plant.

3. Simulation

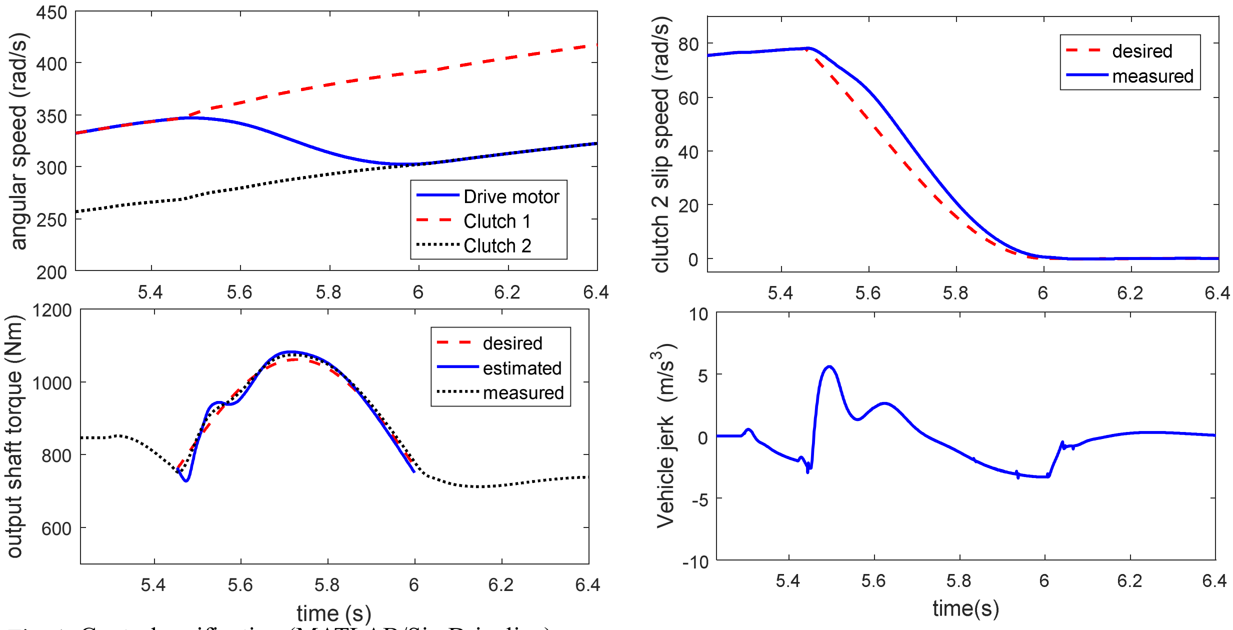

Fig. 1 Control verification (MATLAB/SimDriveline)

Figure 1 describes the control results, which verify good tracking performance of the designed multivariable controller. Using the multivariable control scheme, the speed state as well as the torque state tracked the reference trajectories with precision, which resulted in smooth and fast shift responses.

4. Conclusion

In this paper, a robust multivariable controller is designed to effectively handle the control loop interactions during the gear shift of the HEV with DCT. The effectiveness of the suggested controller is demonstrated through the simulation based on a valid DCT driveline model.

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References

Skogestad, S and Postlethwaite, I., Multivariable feedback control: analysis and design vol. 2 (2007), Wiley New York.

Kim, S. and Choi, S. Control-oriented modeling and torque estimations for vehicle driveline with dual-clutch transmission, Mechanism and Machine Theory, vol. 121 (2018), pp. 633-649.

Kim, S., Oh, J. and Choi, S., Gear shift control of a dual-clutch transmission using optimal control allocation, *Mechanism and Machine Theory,* vol. 113 (2017), pp. 109-125.