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Engine Start-Up Robust Control for a Power-Split Hybrid System Based on μ Synthesis Method

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Abstract

Engine starting control is of great importance for the mode transition process from pure electric mode to electronic-Continuously Variable Transmission (e-CVT) mode for an input power-split system. To suppress the impact of engine start-up on the powertrain, and improve the vehicle ride comfort during the mode transition process, this study proposes an engine start-up robust control strategy based on the μ synthesis method. Firstly, the models of powertrain dynamics and the engine ripple torque (ERT) are established, and the mode transition process is analyzed. Secondly, the engine start-up robust control strategy is proposed to distribute the torque of each power source. The optimal engine cranking speed trajectory is designed based on a dynamic programming algorithm aimed at reducing the engine start-up time and improving the vehicle ride comfort. Finally, to track the optimal engine speed trajectory and the desired power output-end speed, a robust controller is developed based on the μ synthesis method, which considers the system's parametric perturbations and external disturbances. Simulation results on the MATLAB/Simulink platform indicate that the proposed approach can effectively reduce the vehicle longitudinal jerk during the engine starting process and possess superior robust performance against parametric perturbations and external disturbances.

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TABLE 3 Summary of the results.

Case	Longitudinal jerk (m/s^3)	Control deviation (%)
A	13.99	—
B	13.97	0.1
C	14.23	1.7
D	14.66	4.7

References

1. Wu, G., Zhang, X., and Dong, Z., "Powertrain Architectures of Electrified Vehicles: Review, Classification and Comparison," *Journal of the Franklin Institute* 352, no. 2 (2015): 425-448, doi:10.1016/j.jfranklin.2014.04.018.
2. Mashadi, B. and Emadi, S.A.M., "Dual-Mode Power-Split Transmission for Hybrid Electric Vehicles," *IEEE Transactions on Vehicular Technology* 59, no. 7 (2010): 3223-3232, doi:10.1109/tvt.2010.2049870.
3. Kim, J., Kim, T., Min, B., Hwang, S. et al., "Mode Control Strategy for a Two-Mode Hybrid Electric Vehicle Using Electrically Variable Transmission (EVT) and Fixed-Gear Mode," *IEEE Transactions on Vehicular Technology* 60, no. 3 (2011): 793-803, doi:10.1109/tvt.2011.2107564.
4. Hong, S., Kim, H., and Kim, J., "Motor Control Algorithm for an Optimal Engine Operation of Power Split Hybrid Electric Vehicle," *International Journal of Automotive Technology* 16, no. 1 (2015): 97-105, doi:10.1007/s12239-015-0011-8.
5. Liu, D., Yu, H., and Zhang, J., "Multibody Dynamics Analysis for the Coupled Vibrations of a Power Split Hybrid Electric Vehicle during the Engine Start Transition," *Proceedings of the Institution of Mechanical Engineers* 230, no. K4 (2016): 527-540, doi:10.1177/1464419315618862.
6. Hwang, H.Y., "Minimizing Seat Track Vibration That Is Caused by the Automatic Start/Stop of an Engine in a Power-Split Hybrid Electric Vehicle," *Journal of Vibration and Acoustics* 135, no. 6 (2013): 061007.1-061007.8, doi:10.1115/1.4023954.
7. Su, Y., Hu, M., Su, L., Qin, D. et al., "Dynamic Coordinated Control during Mode Transition Process for a Compound Power-Split Hybrid Electric Vehicle," *Mechanical Systems and Signal Processing* 107, no. July (2018): 221-240, doi:10.1016/j.ymssp.2018.01.023.
8. Zhuang, W., Kum, D., Peng, H., Wang, L. et al., "Optimal Engine Starts of an Input-Split Hybrid Electric Vehicle," *SAE Int. J. Alt. Power.* 4, no. 2 (2015): 343-351, doi:https://doi.org/10.4271/2015-01-1227.
9. Zhao, Z., Jiang, L., Wang, C., and Li, M., "Engine Start-Up Optimal Control for a Compound Power-Split Hybrid Powertrain," *Mechanical Systems and Signal Processing* 120 (2019): 365-377, doi:10.1016/j.ymssp.2018.10.027.
10. Wang, C., Zhao, Z., Zhang, T., and Li, M., "Mode Transition Coordinated Control for a Compound Power-Split Hybrid Car," *Mechanical Systems and Signal Processing* 87 (2017): 192-205, doi:10.1016/j.ymssp.2016.10.021.
11. Li, M., Zhao, Z., Jiang, L., and Tang, X., "Subsection Coordinated Control during Mode Transition for a Compound Power-Split System," SAE Technical Paper 2019-01-1214, 2019, doi:https://doi.org/10.4271/2019-01-1214.
12. Zeng, X., Yang, N., Wang, J. et al., "Predictive-Model-Based Dynamic Coordination Control Strategy for Power-Split Hybrid Electric Bus," *Mechanical Systems and Signal Processing* 60-61 (2015): 785-798, doi:10.1016/j.ymssp.2014.12.016.
13. Zeng, X. and Wang, J., "Dynamic Coordinated Control Method of Planetary Hybrid Power-Split System," in *Analysis and Design of the Power-Split Device for Hybrid Systems* (Singapore: Springer Singapore, 2018), doi:10.1007/978-981-10-4272-0_5.
14. Zeng, X., Cui, H., Song, D. et al., "Jerk Analysis of a Power-Split Hybrid Electric Vehicle Based on a Data-Driven Vehicle Dynamics Model," *Energies* 11, no. 6 (2018): 1537, doi:10.3390/en11061537.
15. Lei, W., "Mode Transition Control for Series-Parallel Hybrid Electric Bus Using Fuzzy Adaptive Sliding Mode Approach," *Journal of Mechanical Engineering* 48, no. 14 (2012): 119, doi:10.3901/JME.2012.14.119.
16. Yang, C., Li, L., Jiao, X. et al., "Research on Mode Transition Control for Single-Shaft Parallel Hybrid Powertrain," *Scientia Sinica Technologica* 46, no. 1 (2016): 91-100, doi:10.13140/RG.2.1.4970.6001.
17. Yang, C., Jiao, X., Li, L., Zhang, Y. et al., "A Robust H∞ Control-Based Hierarchical Mode Transition Control System for Plug-In Hybrid Electric Vehicle," *Mechanical Systems and Signal Processing* 99 (2018): 326-344, doi:10.1016/j.ymssp.2017.06.023.
18. Zhang, H., Wang, C., Zhang, Y., Liang, J. et al., "Drivability Improvements for a Single-Motor Parallel Hybrid Electric Vehicle Using Robust Controls," *J. Zhejiang Univ.-Sci.* A15, no. 4 (2014): 291-301, doi:10.1631/jzus.A1300356.
19. Zhang, H., Zhang, Y., and Yin, C., "Hardware-in-the-Loop Simulation of Robust Mode Transition Control for a Series-

Parallel Hybrid Electric Vehicle," *IEEE Transactions on Vehicular Technology* 65, no. 3 (2015): 1059-1069, doi:10.1109/TVT.2015.2486558.

20. 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.

21. Hang, P., Chen, X., Luo, F., and Fang, S., "Robust Control of a Four-Wheel-Independent-Steering Electric Vehicle for Path Tracking," *SAE Int. J. Veh. Dyn., Stab., and NVH* 1, no. 2 (2017): 307-316, doi:https://doi.org/10.4271/2017-01-1584.

22. Madamedon, M., Gu, F., Aburass, A., and Ball, A.D., "Online Estimation of Engine Driveline Dynamic Response," in *2016 International Conference for Students on Applied Engineering*, Tyne, UK, IEEE, 2016, doi:10.1109/ICSAE.2016.7810216.