

Adaptive Update of a Backlash Estimation Observer Based on Online Backlash-Angle Identification for Vibration Suppression in EV Powertrains

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Electric vehicle (EV) powertrains have high torque responsiveness and low acoustic noise. However, torsional vibration caused by driveshaft elasticity and gear backlash becomes noticeable during torque reversals. In such situations, the gear teeth repeatedly transition between contact, free-motion, and re-contact states, resulting in discontinuous torque transmission. Therefore, accurate estimation of backlash-related states is important for vibration suppression and drivability improvement.

The authors have previously developed a backlash estimation observer for an EV powertrain modeled as a two-inertia system with nonlinear backlash. The observer estimates internal states such as torsional torque and backlash displacement by considering the switching behavior between Contact Mode and Backlash Mode. However, the backlash angle must be given as an internal observer parameter. If this parameter differs from the actual backlash angle, errors occur in the estimated contact boundary, free-motion interval, and re-contact timing.

This study proposes an observer parameter update method based on online backlash-angle identification. In the proposed method, the free-motion interval is detected using the estimated torsional torque obtained from a disturbance observer. The backlash angle is then identified from the change in the estimated relative displacement angle during the detected interval. To reduce the influence of noise and event-to-event variation, the identified value is stabilized through multiple valid free-motion events and then used to update the backlash-angle parameter of the observer.

Numerical simulations were conducted using a two-inertia EV powertrain model with backlash. The simulator is based on a high-fidelity exact backlash simulator whose consistency with vehicle experimental results has been confirmed in previous work. The proposed identification method was applied to 200 simulation conditions with different backlash angles. Fig.1 shows the identification results of the backlash angle. The final signed relative error had a mean value of 3.20 % and a standard deviation of 5.72 %. The mean and median absolute relative errors were 5.29 % and 4.34 %, respectively. In addition, 87.5 % of the cases converged within 10 %, and 97.5 % converged within 15 %.

To evaluate the observer update effect, a representative condition with a true backlash angle of 0.0141 rad was analyzed. Before the update, the observer parameter was 0.0058 rad, corresponding to a 58.87 % underestimation. The stabilized identified value was 0.0134 rad, reducing the relative error to 4.96 %. Fig.2 shows the estimated torsional torque before and after the observer parameter update. Before the update, the estimated free-motion interval was shorter than the true interval because the observer contact boundary was narrower than the actual backlash width. After the update, the estimated zero-torque interval became closer to the true interval.

For six free-motion events, the mean absolute error of the Contact Mode return timing was reduced from 12.85 ms to 2.41 ms. The estimated mean free-motion duration also improved from 11.50 ms to 26.00 ms, approaching the true mean duration of 28.04 ms. These results confirm that the proposed online backlash-angle identification and observer parameter update reduce mode-transition estimation errors caused by backlash-angle parameter mismatch.

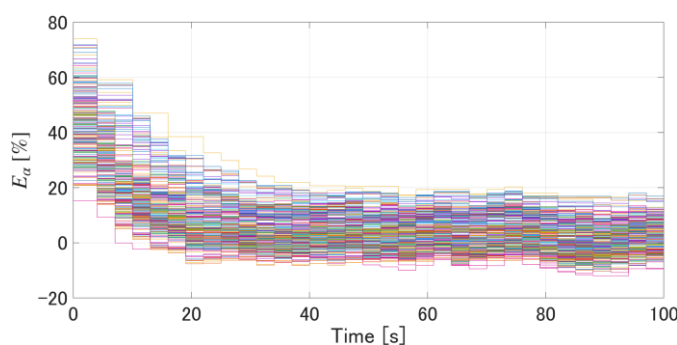


Fig.1 Identification results of backlash angle for 200 simulation conditions

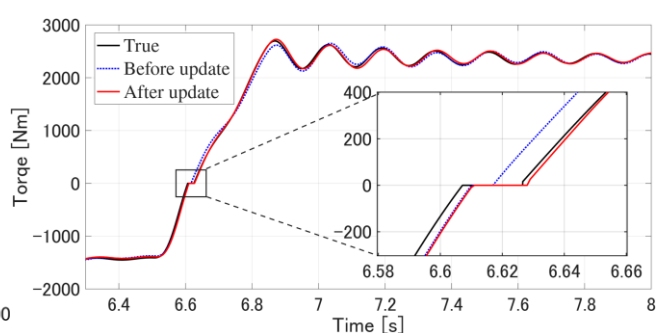


Fig.2 Comparison of estimated torsional torque before and after observer parameter update