

Proposal of an EV CVT Control Map and Comparison under Various Driving Cycles Based on Optimal CVT Ratio Analysis

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Improving the energy efficiency of electric powertrains is important for reducing the energy consumption and extending the driving range of battery electric vehicles (BEVs). In particular, for high-speed motors, an appropriate transmission ratio should be selected according to the vehicle operating condition so that the motor can operate in a high-efficiency region. A continuously variable transmission (CVT) enables continuous adjustment of the transmission ratio and therefore has the potential to improve the efficiency of a BEV powertrain. However, its performance strongly depends on the CVT ratio control strategy.

In this study, a new CVT control map was developed based on the distribution characteristics of the instantaneous optimal CVT ratio. The Motor A powertrain connected to the CVT was considered, and the CVT ratio that minimized the instantaneous battery power consumption was calculated at each time step under the Worldwide harmonized Light vehicles Test Cycle (WLTC). The calculation considered the losses of the motor, CVT, gears, and bearings. Dynamic programming considering the CVT ratio change-rate constraint showed only a small difference from the instantaneous optimization.

To analyze the characteristics of the optimal CVT ratio, the required tire torque was divided into inertial torque and running resistance torque, and their ratio, T_{ir} , was introduced as an analysis index. The analysis revealed different distribution characteristics between the traction and regenerative regions. In the traction region, the optimal CVT ratio consisted of a continuously varying sloped region and several fixed-ratio regions. In the regenerative region, a continuous sloped region was mainly observed together with maximum- and minimum-ratio regions. The continuous regions were found to depend on both T_{ir} and vehicle speed.

Based on these characteristics, quadratic surface approximation using Random Sample Consensus (RANSAC) was applied to the continuous-ratio regions in both traction and regeneration, while Support Vector Machine (SVM) classification was applied to the fixed-ratio regions in traction. At vehicle speeds below 12 km/h, the CVT ratio was fixed at the maximum ratio of 1.732. By integrating these regions, the proposed CVT control map shown in Fig. 1 was constructed.

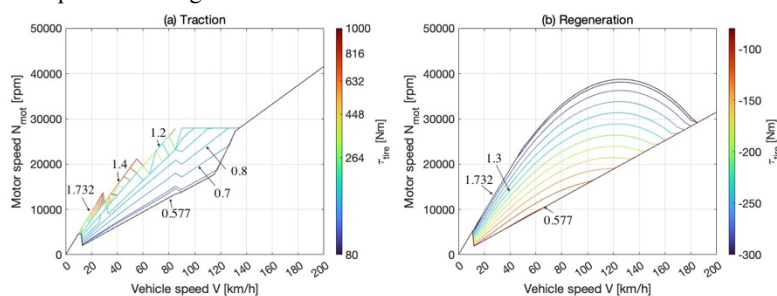


Fig. 1 Proposed CVT control map

The proposed map was evaluated under four driving cycles: WLTC, JC08, UDDS, and HWFET. In all driving cycles, the proposed map reduced battery energy consumption compared with the current CVT control map. For WLTC, the battery energy consumption during traction decreased from 3.6302 kWh to 3.6185 kWh, while the regenerated battery energy slightly increased from 0.9301 kWh to 0.9311 kWh. Similar improvements were obtained for JC08 and UDDS. The improvement was mainly attributed to reduced battery energy consumption in the traction region, particularly under driving conditions involving frequent acceleration and deceleration at low and medium vehicle speeds. In contrast, the improvement under HWFET was relatively small because this cycle mainly consists of high-speed cruising.

These results demonstrate that analyzing the distribution characteristics of the instantaneous optimal CVT ratio provides an effective approach for constructing a practical CVT control map. The proposed map successfully reflects the different characteristics of the traction and regenerative regions and reduces battery energy consumption under different driving cycles while achieving performance close to the instantaneous optimal solution.