Optimizing Electric Energy Consumption on Longitudinal Motion Planning for EV Cruising Task

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In this paper, we study to optimize electric energy consumption on motion planning for EV cruising task. We optimize a longitudinal motion plan shown in Fig. 5, in which the speed changes in a triangular wave pattern around the cruising speed considering effective use of the electric power transfer efficiency.

In such a problem, the pulse-and-glide (PnG) strategy, a motion plan that alternately combines acceleration using the maximum efficiency point of the gasoline engine and deceleration by coasting, is known to be effective for engine vehicles. However, in the case of EVs, it was theoretically unclear whether the PnG strategy is optimal, since there is also regeneration.

Therefore, in the motion plan shown in Fig. 5, depending on the motor torque T_{MD} during the deceleration interval, we divided the cases into (i) power running $T_{MD} > 0$, (ii) $T_{MD} = 0$, and (iii) regeneration $T_{MD} < 0$, and derived a numerical model of energy consumption per meter traveled in each case (Eqns.30-33).

Using these models, we theoretically showed that there is always a plan of (ii), which consumes less energy than any plan of (iii), and that the plan that includes regeneration cannot be optimal in terms of energy consumption. In addition, for plans of (i) and (ii), the sufficient condition for the plan of (ii) to be optimal is shown. If the PnG strategy can be taken on the motor efficiency map as shown in Fig. 6, this sufficient condition is met and the PnG strategy is optimal (Fig. 8).

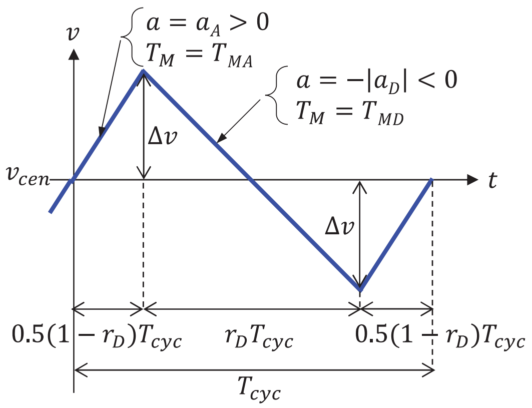

Fig.5 Speed pattern with asymmetrical acceleration and deceleration maintaining cruising speed

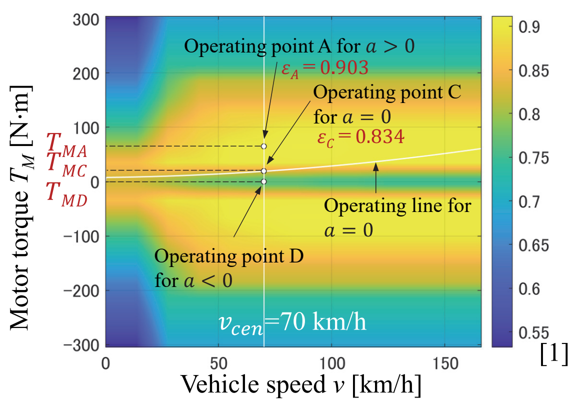

Fig.6 Motor efficiency map with operating points of an asymmetrical acceleration and deceleration speed pattern maintaining cruising speed

$$k_A := \frac{T_{MC} - T_{MD}}{T_{MA} - T_{MD}} \cdot \frac{T_{MA}}{T_{MC}} \quad (30) \qquad \begin{array}{ll} 0 < k_A < 1 & \left((\mathrm{i})\ 0 < T_{MD} < T_{MC}\right) \\ k_A = 1 & \left((\mathrm{ii})\ T_{MD} = 0\right) \\ 1 < k_A & \left((\mathrm{iii})\ T_{MD} < 0\right) \end{array}$$

$$E_{bttry/dist} = \begin{cases} \dfrac{2\gamma}{d} \cdot \left(k_A \cdot \dfrac{T_{MC}}{\varepsilon_A} + (1 - k_A) \cdot \dfrac{T_{MC}}{\varepsilon_D} \right) & \left((\mathrm{i})\ 0 < T_{MD} < T_{MC}\right) \quad (31) \\ \dfrac{2\gamma}{d} \cdot \dfrac{T_{MC}}{\varepsilon_A} & \left((\mathrm{ii})\ T_{MD} = 0\right) \quad (32) \\ \dfrac{2\gamma}{d} \cdot \left(\dfrac{T_{MC}}{\varepsilon_A} + (k_A - 1) \cdot \left(\dfrac{1}{\varepsilon_A} - \varepsilon_D \right) T_{MC} \right) & \left((\mathrm{iii})\ T_{MD} < 0\right) \quad (33) \end{cases}$$

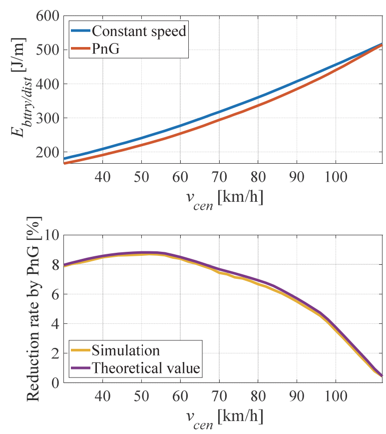

Fig.8 Energy consumption per meter traveled for constant speed and PnG strategy for each cruising speed (top figure) and reduction rate by PnG strategy (bottom figure)

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