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Integrated Pitch Damping Control Considering Control Device Characteristics for Compatibility of Acceleration Feeling and Ride Comfort

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One of the key attributes of electric vehicles is their strong sense of acceleration, which has been reported to be enhanced by high longitudinal jerk during acceleration as well as by suppression of vehicle pitch rate. Owing to the high responsiveness of traction motors, electric vehicles can readily generate high longitudinal jerk. At the same time, such high longitudinal jerk induces a large pitch moment, thereby necessitating effective pitch rate suppression. Various approaches for pitch rate suppression have been reported, including traction motor-based control, suspension design optimization, and semi-active suspension control. Nevertheless, these methods generally involve trade-offs with driving force performance or ride comfort. In this paper, an integrated pitch damping control strategy is proposed that accounts for the device characteristics of both the traction motor and the semi-active suspension, with the aim of achieving a balance between a strong sense of acceleration and ride comfort. The effectiveness of the proposed method is demonstrated through simulations and vehicle experiments.

Because a traction motor can control torque with high precision and fast response, it is possible to realize pitch damping control without excessively suppressing longitudinal jerk. However, an excessive damping demand may cause delays or oscillations in the driving force response. Therefore, the traction motor is suitable for providing a relatively small amount of pitch damping in the normal operating region.

A semi-active suspension (AVS) can generate passive damping forces according to suspension stroke velocity. As a result, its pitch control effect is limited in low-acceleration regions where longitudinal jerk is small, and increasing the damping force leads to a trade-off with ride comfort. Consequently, the AVS is preferably utilized mainly during large acceleration and deceleration events that generate high longitudinal jerk.

Considering these device characteristics, this paper proposes an integrated pitch damping control concept, as illustrated in Fig. 1. As shown in Eq. (1), for the required pitch moment M_{yc} to achieve the target vehicle pitch damping, the traction motor generates a pitch moment M_{yTM} within a range that does not conflict with driving force response. The remaining pitch moment is then allocated to the AVS as M_{yAVS}. By distributing the pitch moment in this manner, integrated pitch damping control that accounts for the characteristics of each device can be realized.

$$M_{yAVS} = M_{yc} - M_{yTM}. \qquad (1)$$

Fig. 2 shows the results of the full-vehicle simulation. The performance is compared between the case where the same pitch damping target is achieved using only the AVS and the case where it is achieved using the proposed integrated pitch damping control. As intended, the integrated pitch damping control achieves greater pitch suppression while requiring a smaller AVS control effort.

Fig. 3 presents the results of vehicle tests conducted on a random road. The power spectral density (PSD) of the vertical acceleration at the vehicle center of gravity is compared. By reducing the AVS control effort, the integrated pitch damping control suppresses the increase in PSD in the secondary ride frequency range above 10 Hz, thereby achieving both improved acceleration feel and ride comfort.

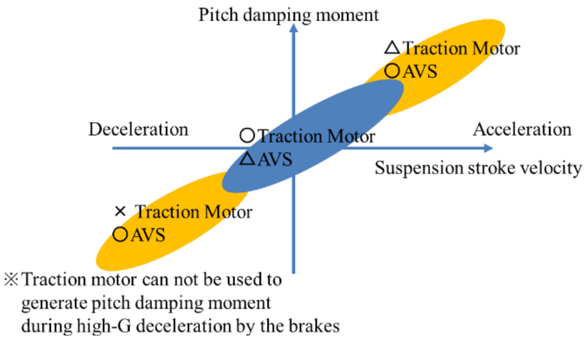

Fig. 1 Concept of Integrated Pitch Damping Control.

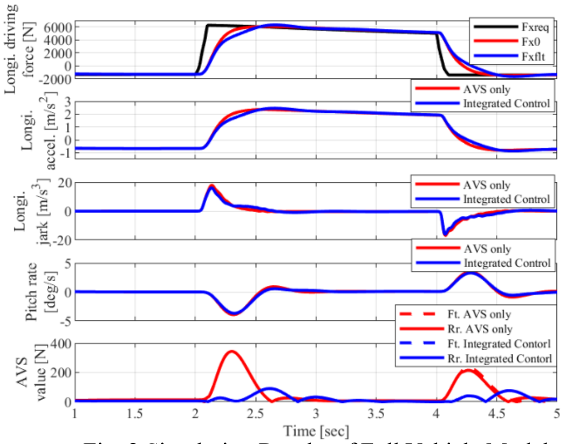

Fig. 2 Simularion Results of Full Vehicle Model (Accel. 50%).

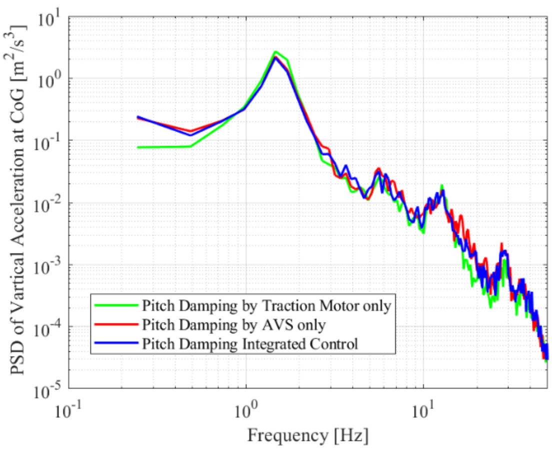

Fig. 3. PSD of Vertical Acceleration on CoG.