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Studies on Vehicle Motion Control using a Traction Motor in Electrified Vehicles

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Executive Summary

This paper presents a practical approach of a vehicle motion control using a traction motor for electrified vehicles. In the electrified vehicles, highly responsive electric motor can assist the conventional suspension system to generate squat and dive motion intentionally, since the electric motor can precisely control the vehicle load shift from front wheels to rear ones or vice-versa. The proposed control system consists of 3 main parts: handling control, ride comforts control and traction control. In the lane change, proposed controller conducts the vehicle load shift and provides fast and stable handling performance. In the speed bump and acceleration driving, the proposed controller conducts the vehicle load shift to minimize the pitching motion and provides ride comfort. Under wheel slip situation, the proposed controller conducts anti-slip control and provides stable driving and steering. The superiority of the vehicle motion control proposed in this paper was confirmed through vehicle experiment.

Keywords: EV, HEV, vehicle motion control, handling performance, ride comfort, traction control

1 Introduction

This paper presents a traction motor based motion control for Electrified vehicles. Using the phenomenon that nose up/down occurs when the vehicle accelerates/decelerates, highly responsive electric motor can precisely control the vehicle's load shift from front wheels to rear ones or vice-versa regarding the driving situations for better handing performance, ride comfort and traction performance. Figure 1 illustrates the load shift behavior of the vehicle according to the motor torque output in the front wheel drive vehicle.

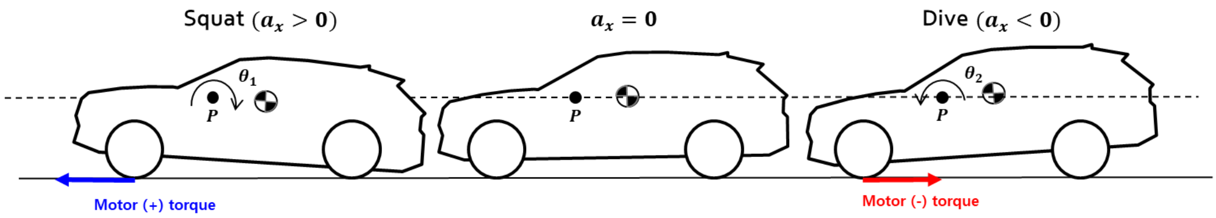

Figure1: Load shift behaviour of vehicle according to motor torque output

In this study, based on the control of the pitch behavior of the vehicle according to motor torque control, it is proposed to control the improvement of ride comfort, handling performance and traction performance as shown in Figure 2. When passing a bump or accelerating, the pitch fluctuation of the vehicle occurs, and at this time, the change in pitch behavior is reduced through motor control to improve ride comfort. In situations where fast and stable steering control is required, such as lane changes, the front and rear load movement control of the vehicle is performed through motor control, enabling front and rear tire grip control. When starting the vehicle and circling, the motor torque reduction control can be controlled to use the driving force within the maximum grip limit of the tire to reduce wheel slip and improve traction. The following sections introduce detailed control strategies and test results of traction motor-based vehicle motion control.

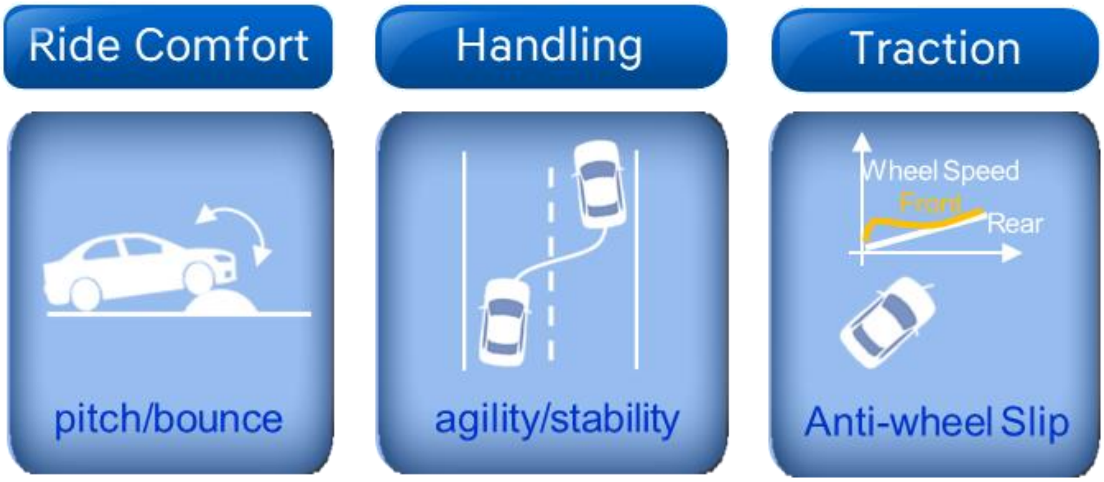

Figure2: Overview of vehicle motion control using a traction motor

2 Traction Motor based Vehicle Motion Control System

2.1 Overview

The traction motor based vehicle motion control system consists of 3 main parts: ride comfort control, handling control, and traction control. This section introduces detailed control strategies for three parts of traction motor-based vehicle motion control.

2.2 Ride comfort control

When the vehicle crosses a speed bump, the driver or passenger feels uncomfortable due to the shaking in the pitch direction. In addition, when the driver presses the gas pedal or activates the cruise control to start accelerating, the front of the vehicle is lifted and the passenger's head is tilted back, which may cause inconvenience to passengers.

This study proposes a vehicle motion control method to improve riding comfort in the two situations described above when passing a speed bump and when the vehicle accelerates. Figure 3 conceptually shows traction motor-based ride control. Depending on the control amount of motor torque, the pitch motion can be reduced when passing through the bump and when accelerating. The motion controller recognizes road surface conditions such as speed bumps and acceleration driving conditions, estimates the rate of change of the pitch angle of the vehicle, and calculates a motor torque command to minimize the rate of change of the pitch angle. When the front of the vehicle is raised, the motor torque in the negative direction is output to cause nose-down, and when the rear of the vehicle is raised, the motor torque is output in the positive direction to generate the nose-up. Figure 3 describes the control structure of the ride comfort control in this paper.

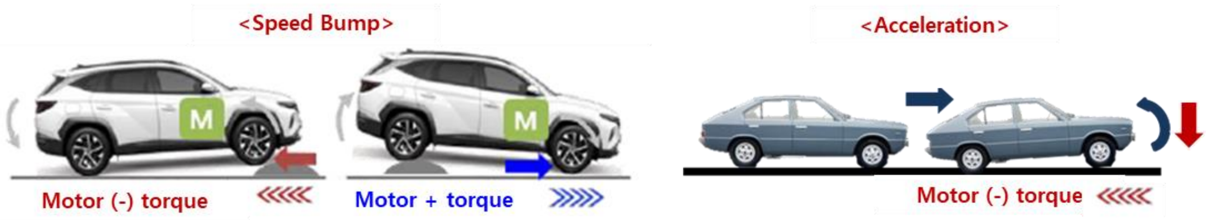

Figure3: Concept of ride comfort control

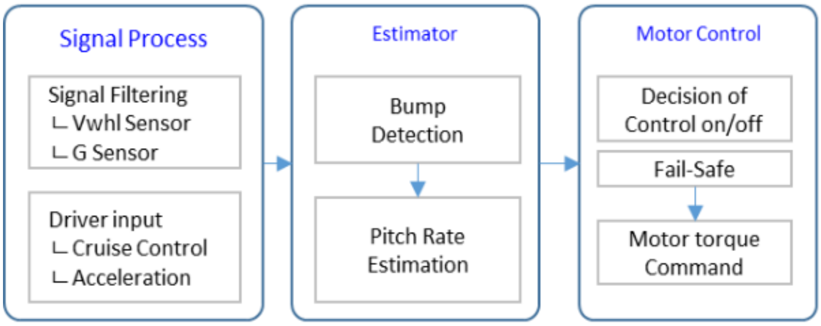

Figure4: Structure of ride comfort control

2.3 Handling control

In a situation in which the driver manipulates the steering wheel to change lanes, the vehicle must move agilely in conjunction with the steering wheel manipulation. In addition, when the lane change is complete, the vehicle should maintain a stable posture without rolling and diagonal action.

In this study, driving motor control is performed to realize agile and stable handling performance in a lane change situation. Figure 5 conceptually shows traction motor-based handling control. When entering a turning, the motor torque is applied in the negative direction to increase the vertical force of the turning wheel to improve the responsiveness at the time of turning, and at the end of turning, the motor torque is applied in the positive direction to increase the vertical force of the rear wheel, increase stability[1,2]. As shown in Figure 6, the vehicle motion controller consists of three main parts. In the signal processing part, signal processing is performed for driver input such as steering angle. In the estimator part, the vehicle speed, lateral acceleration and lateral jerk are estimated to estimate the tire force required for handling. Finally, there is a part that determines the torque of the traction motor based on the results of the estimator.

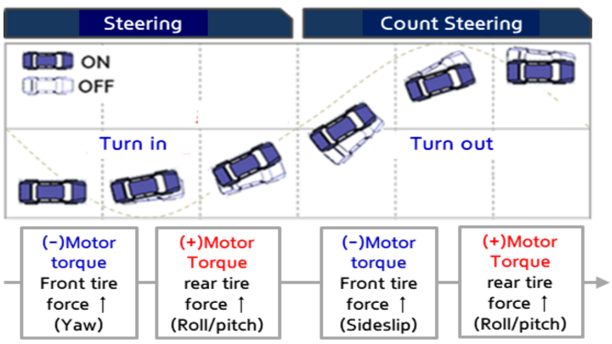

Figure 5: Concept of handling control

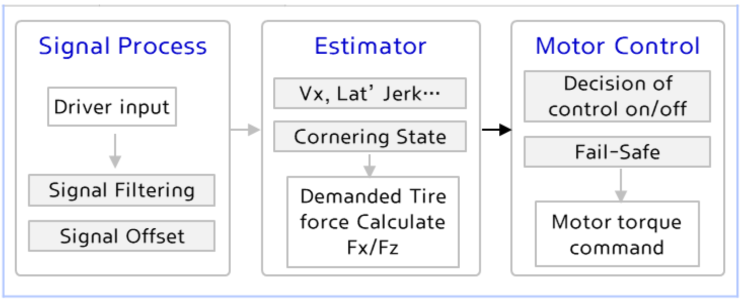

Figure 6: Structure of handling control

2.4 Traction Control

In this paper, we propose a wheel slip prevention control based on a driving motor[3]. The proposed traction controller estimates maximum traction torque and adjusts driving torque using a traction motor. The proposed traction controller is effective to improve driving performance under high acceleration demand not only launching the vehicle but also cornering the vehicle. It maximizes traction torque and minimizes understeer behaviour in the cornering case.The overview of the traction control system is shown in Figure 7 and Figure 8.

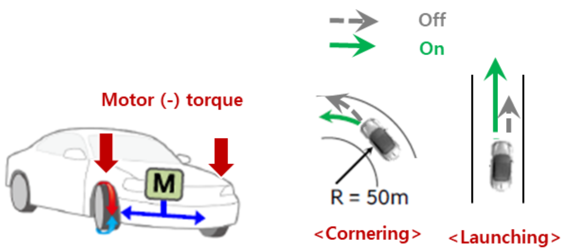

Figure 7: Concept of traction control

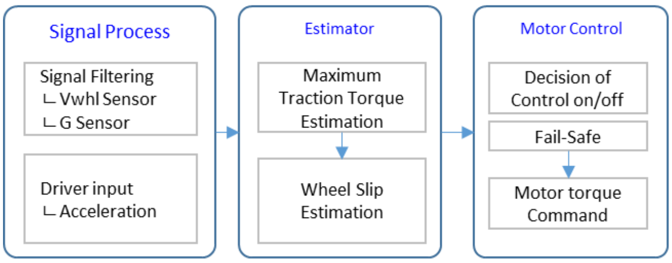

Figure 8: Structure of traction control

3 Vehicle experiment

Vehicle experiment has been conducted in the mid-size sport utility front wheel drive hybrid electric vehicle. As a result of the vehicle experiment, the proposed vehicle motion control achieved better handling performance, ride comfort and traction performance under lanechange, speed bump/acceleration and cornering/launching condition with high acceleration demand, respectively. Summary of experimental result is briefly shown in Table 1 and detail experimental results for each item is shown as the following subsections.

Table 1: Summary of experimental result

Item	Result
Handling	Yaw Rate (9.7% ↑) Side Slip Angle (13% ↓)
Ride comfort	Bump: Pitch Rate (16.8% ↓) Acceleration: Pitch Rate (40% ↓)
Traction	Wheel Slip (79% ↓) Yaw Rate (18% ↑)

3.1 Handling control

The test is carried out in a lane change situation when driving at 80 km/h. To evaluate the proposed traction motor-based handling control performance, measure the difference between yaw rate and side slip angle in control On and OFF situations. The test results showes that the performance of the proposed controller is superior in terms of steering responsiveness during turn-in and steering stability during turn-out, quantitatively.

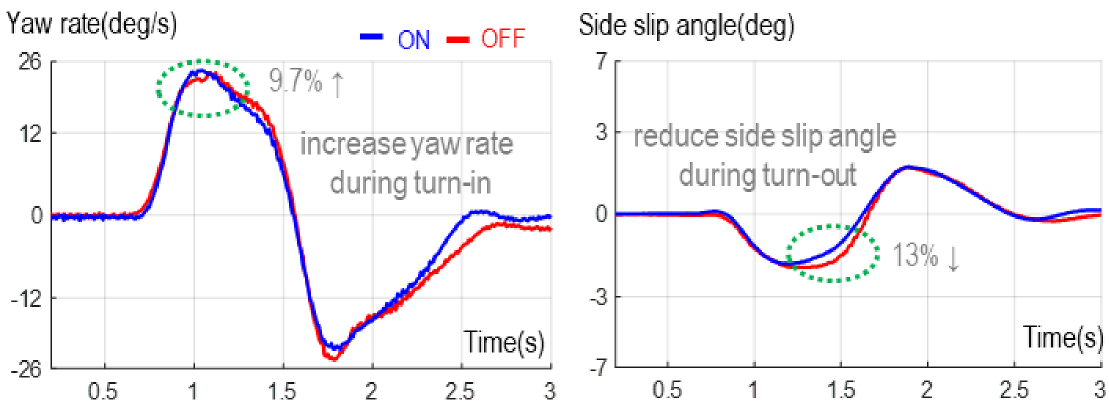

Figure 9: Experimental result of handling control

3.2 Ride comfort control

For the evaluation of ride comfort control when passing speed bumps and dips, the pitch behavior when controlling on and off is compared while driving at a speed of 40 km/h. As shown in Figure 10, when the proposed traction motor-based ride controller is applied, it can be seen that the value of the pitch rate is reduced when passing through bump and dip. In particular, aftershocks continue after bumps and dips, and test results show that this part is also reduced when the proposed controller is used.

In addition, the results of the evaluation of ride comfort in the acceleration situation confirmed that the performance of the proposed controller is excellent. Figure 11 shows the change in demand torque and the behavior of pitch rate before and after control application. The proposed traction motor-based ride control reduces the required torque for a short period of time and reduces the pitch rate by 40%.

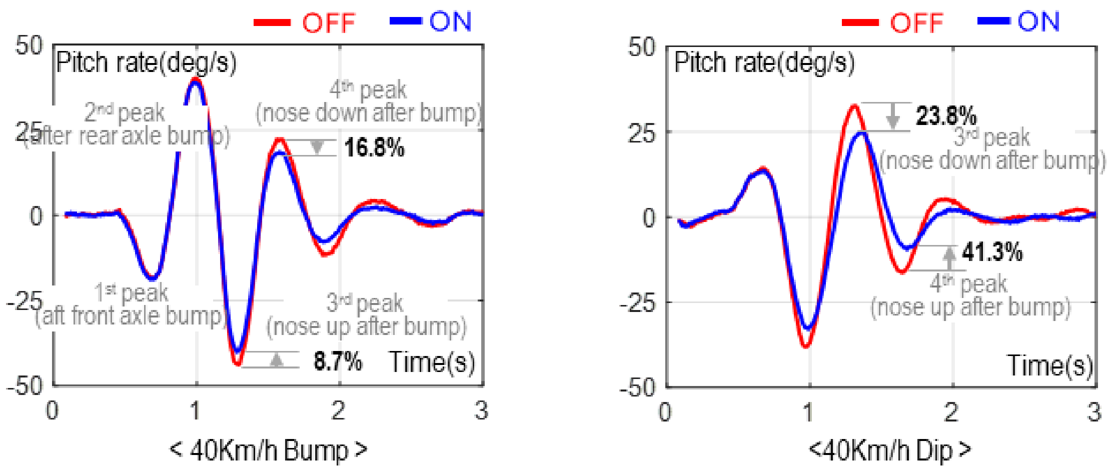

Figure 10: Experimental result of ride comfort control (bump and dip)

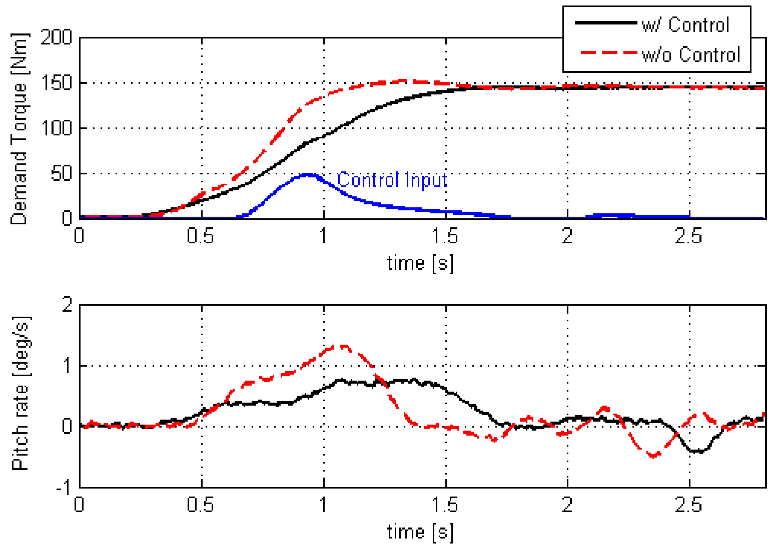

Figure 11: Experimental result of ride comfort control (acceleration)

3.3 Traction control

In order to comprehensively evaluate the traction control performance, the performance of the proposed controller is checked under the condition of driving at 70 km/h on a circular road with a radius of 50 m. Figure 12 shows the speed difference and yaw rate of the two driving wheels depending on whether the proposed controller is activated during circular driving. When the proposed controller is not operating, the grip of the wheel on the outside side of the turn is weakened, resulting in slip, which reduces the yaw rate and causes the understeer phenomenon. On the other hand, when the proposed controller is operating, slip of the outer wheel of the turning does not occur through precise control of the traction motor, so that the yaw rate does not decrease, thereby reducing the understeer phenomenon. The proposed controller maximizes traction by controlling the wheel slip of the drive wheel with a traction motor, even in the situation of a straight vehicle start.

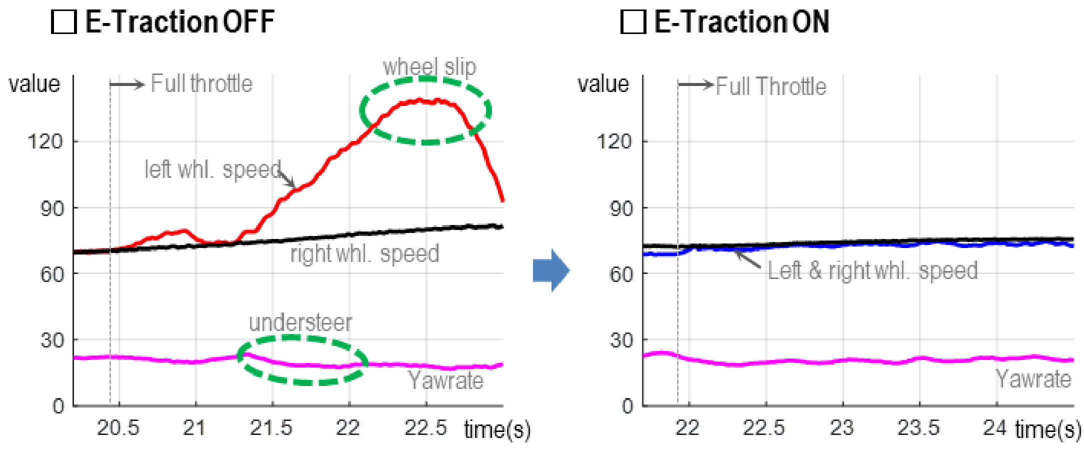

Figure 12: Experimental result of traction control (cornering)

4 Conclusions

This paper introduces several studies about traction motor based motion control system to improve handling performance, ride comfort and traction performance for electrified vehicles. From the vehicle experiment, we achived good performance by a traction motor without any cooperative control with chassis components. In a future study, we intend to conduct a study to optimize driving performance by combining the proposed controller with existing chassis components such as an electrically controlled suspension and a friction braking system. Moreover dual-motor application is considered to improve handling performance, ride comfort and traction performance.

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Presenter Biography

Dr. Sangjoon Kim received the B.E degree in electrical engineering from Hanyang University , Seoul, Korea in 2006 and he received the PhD in the same department from Hanyang University in 2022. In 2006, he joined the Electrification Control System Development Team of R&D Division, Hyundai Motor Company, as a Research Engineer, and he has been working for vehicle controller development such as Engine Control Unit (ECU), Hybrid Electric Vehicle Control Unit (HCU), Electric Vehicle Control Unit (VCU). In 2021, he became a Leader of xEV Control Development Part which is in charge of vehicle platform controller (VPC) project for mass production of xEV and development of vehicle motion control features. His current research interests include vehicle-level control system integration, and vehicle motion control, AI based control application and agile and efficient control system development for mass production.