Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

STEERING ASSIST TORQUE CONTROL ENHANCING VEHICLE STABILIITY

AhnNa Lee*, JiHyun Jung, BonGyeong Koo***, HangByoung Cha******

**National Institute of Standards and Technology, Boulder, CO 80305 USA (Tel: 82-31-300-5267; e-mail: B02793@mando.com).*
**National Institute of Standards and Technology, Boulder, CO 80305 USA (Tel: 82-31-300-5311-mail: jihyun@mando.com).*
****Colorado State University, Fort Collins, CO 80523 USA (Tel: 82-31-300-5241; e-mail: bgkoo@mando.com)*
***** Electrical Engineering Department, Seoul National University, Seoul, Korea, (Tel: 82-31-300-5020-mail: hbcha@mando.com)}*

Abstract: The usage of electronically controlled systems is recently in the trend of increase. Electronically controlled systems for the vehicle are communicated through the network as CAN (Control Area Network) among individual electronic control systems. By sharing sensor and processing signals through the network among individual electronic control systems, Unified Chassis Control (UCC) which control individual electronic control systems at the same time can be possible. This paper presents Unified Chassis Control System of Electronic Stability Control (ESC) System and Electric Power Steering (EPS) System for improving vehicle dynamic stability. Unified Chassis Control improves vehicle stability by steer intervention to assist driver's maneuverability. ESC detects vehicle-stability and driver-maneuvering through the sensor and processing signals and judges whether steer assist torque intervene for improving vehicle stability. If steer intervention is needed to control vehicle, a motor of EPS generates calculated steering assist torque for steer intervention which is transferred through the network. We demonstrated that Unified Chassis Control improves the vehicle stability by several vehicle tests such as braking or accelerating on Split – μ roads and on under-steer or over-steer condition.

1. INTRODUCTION

With progress of electronic technology, electronic control systems for vehicle are developed and increased in use. Individual electronic control systems for the vehicle are communicated through the network as CAN (Control Area Network). Sharing sensor and processing signals through the network among individual electronic systems without additional sensors develop Unified Chassis Control.

This paper mentions Unified Chassis Control of Electronic Stability Control (ESC) System and Electric Power Steering System (EPS). Unified Chassis Control improves vehicle stability to compensate vehicles moment by generating steering assist torque. ESC detects and judges environmental condition, vehicle dynamic state which is on Split – μ roads or over-steer / under-steer through information from Yaw rate Sensor, Lateral G Sensor, SAS (Steering Angle Sensor) and Wheel Speed Sensor. ESC calculates appropriate steering assist torque for maintaining and improving vehicle stability and steer-ability. Calculated steering assist torque to control vehicle is transferred into EPS via CAN.

The vehicle is maintained stable and controllable so as to generate steering assist torque by electric motor of EPS under the control of ESC.
In this way Unified Chassis Control which is integrating Individual Chassis control systems improves vehicle performance such as vehicle stability, driver's maneuverability, etc.

2. UNIFIED CHASSIS CONTROL SYSTEM OF ESC & EPS

2.1 UCC System Configuration

Fig. 1 shows a configuration of vehicle which is used for study. Test vehicle is equipped with ESC system, column-type EPS system and Sensors. ESC detects environment and vehicle state through information from Yaw rate Sensor, Lateral G Sensor, SAS (Steering Angle Sensor), Wheel Speed Sensor and judge over-steer or under-steer. If ESC judge vehicle is on over-steering or under-steering condition, it controls vehicle braking and traction force of individual tires by Brake Control and Engine Control for reducing braking distance and improving steer maneuverability.

978-1-1234-7890-2/08/$20.00 © 2008 IFAC

10.3182/20080706-5-KR-1001.3362

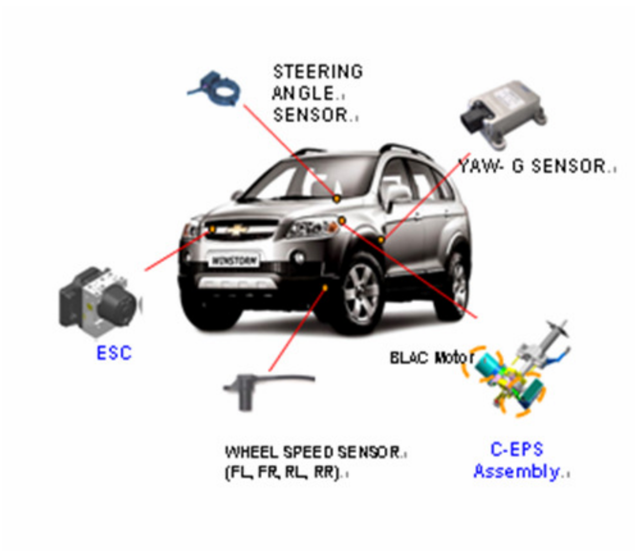


Fig. 1. Chassis Control System Architecture

EPS detects steering torque by Torque Sensor, which is placed between the steering wheel and motor and steering wheel velocity from Motor Position Sensor. According to detected steering torque and vehicle velocity signals, EPS controls torque of electric motor (which is equipped in EPS) to assist the steering effort. Generally, EPS motor generates large assist torque on parking or in the low speed, so steering effort is light. Also, EPS motor generates small assist torque in the high speed, so steering effort is heavy.

As show in Fig.2, ESC and EPS of Unified Chassis Control (UCC) System communicate sensor and processing signals via CAN.

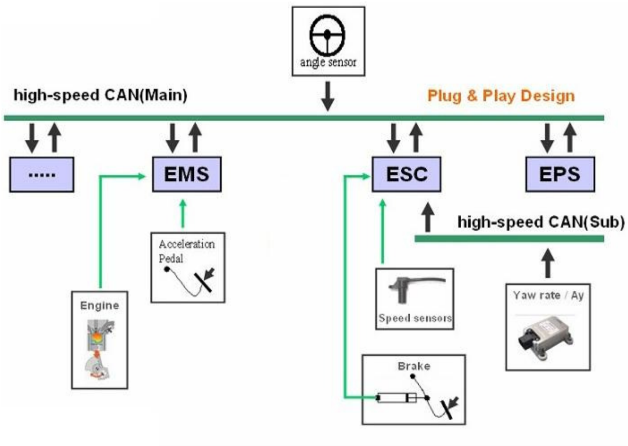


Fig. 2. UCC System Architecture

Fig. 3 shows control algorithm of Unified Chassis Control System. By integrating Individual Chassis control systems, Unified Chassis Control system controls vehicle dynamic characteristics more efficiently than Individual Chassis control system.

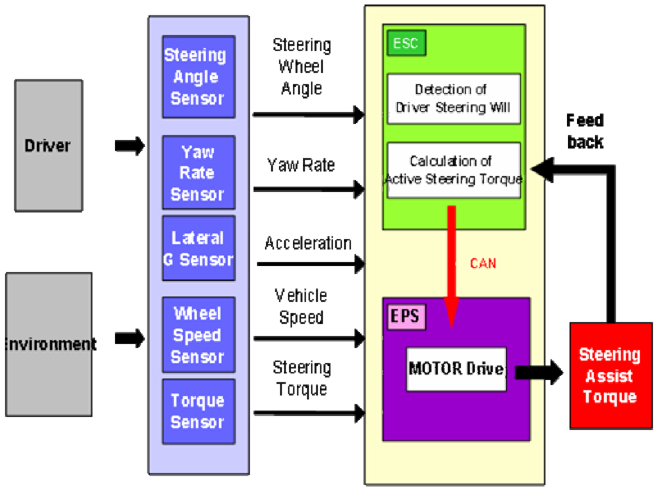


Fig. 3. Unified Chassis Control Algorithm

As mentioned above, Fig. 3 shows Steering assist Torque Control algorithm of Unified Chassis Control(UCC) system which is consisted of ESC System and EPS System.

By getting information through communication between ESC System and EPS System, ESC System judges environment conditions as friction of road, vehicle state as under-steer or over-steer and driver's steering behaviour as turning or fast steering for avoiding danger. Here, Driver's steering behaviour is judged by signals of driver input torque, steering angle and steering angular velocity. ESC decides appropriate Steering assist Torque for improving vehicle stability and signal of Steering assist Torque is transferred into EPS via CAN.

As shown in Fig. 4, EPS System controls electric motor to generate Steering assist Torque which is calculated in ESC electric unit. By assist driver steering maneuverability using Steering assist Torque, vehicle stability is improved.

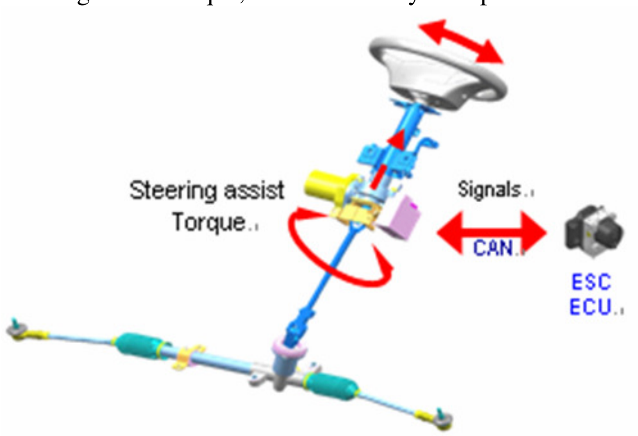


Fig. 4. Chassis Control System Mechanism

Then, it is important that Driver's steering is prior than steering by Unified Chassis Control System. Steering by steering assist torque should not disturb driver's maneuverability when steering assist torque control is not against driver's steering, steering assist torque control is activated.

2.2 Control Strategy

There are Split- μ Stability Control for compensating yaw moment on the Split-μ road and Handling Stability Control for assisting driver's maneuverability on over-steer or under-steer in Steering assist Torque Control.

2.2.1 Split-μ Stability Control

2.2.1.1 Split-μ Braking Mode

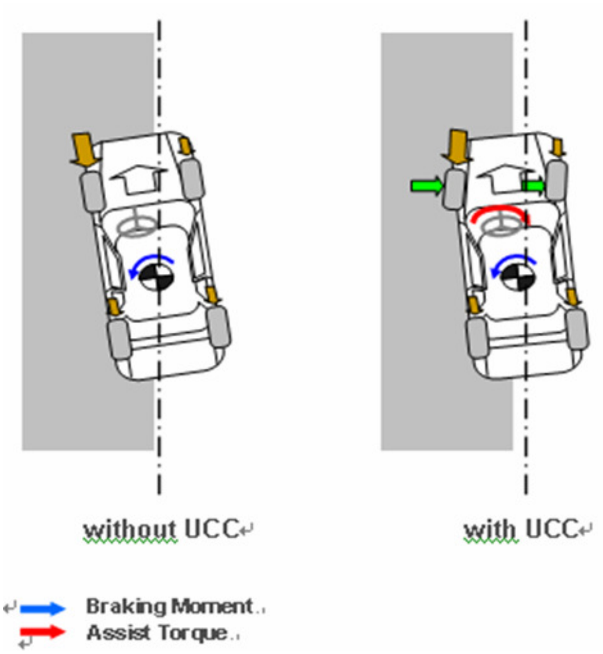


Fig. 5. Split-μ Stability Control Concept

As shown in Fig.5, braking force between right and left wheel is different in case of braking on the Split-μ road. Braking force of wheel on the High-μ is larger than braking force of wheel on the Low-μ. Yaw moment of vehicle is generated counter-clockwise through difference of braking force between right and left wheel. If the driver dose not counter – steer appropriately, in spite of activating ESC, the vehicle deflects toward the high friction side. At this situation, Unified Chassis Control System detects stability of vehicle on the Split-μ road and decides whether steer intervention is. Then it helps the driver to counter – steer appropriately by generating proper steering assist torque which is in the direction of Low-μ road.

As shown in Fig.6, ESC calculates moment of vehicle using delta yaw (difference of yaw rate which is calculated from vehicle model and yaw rate which is measured Yaw Rate sensor) and delta - pressure which estimated from braking force difference between right and left wheel. Then ESC calculates appropriate steering assist torque to compensate yaw moment of vehicle. Electric motor EPS generates steering assist torque which is transfer via CAN. By providing suggestive torque to stabilize vehicle, Unified Chassis Control System help the vehicle to be braked longitudinally.

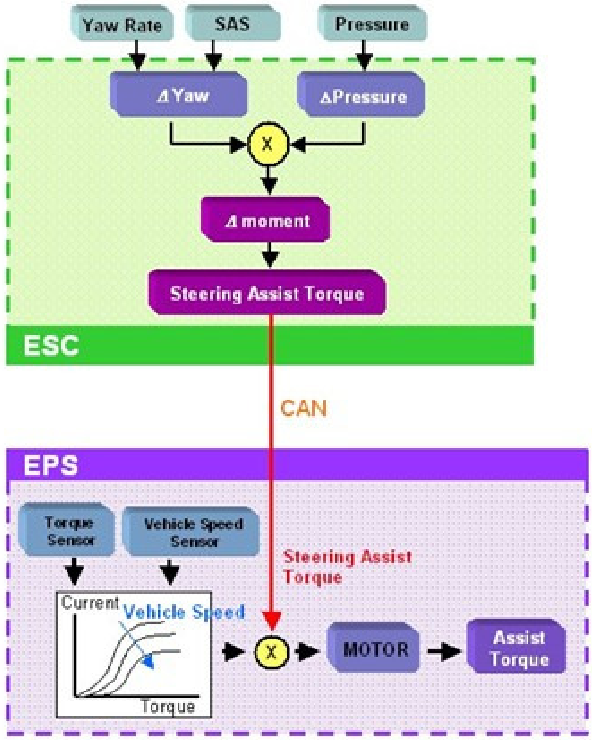


Fig. 6. Split-μ Braking Mode Algorithm

2.2.1.2 Split-μ Accelerating Mode

If vehicle is accelerated on the Split-μ road, traction force between right and left wheel is different. Traction force of wheel on the Low-μ road is small and the tire road skidded on Low-μ. Because of traction force difference between right and left wheel, moment of vehicle is generated in the direction of from High -μ to Low -μ. As braking on the Split-μ road, if the driver dose not counter – steer appropriately, the vehicle deflects toward the low friction side. In case of Split-μ accelerating, yaw moment is not generated much as Split -μ braking. ESC calculates steering assist torque to compensate moment of vehicle. Then electric motor of EPS generates steering assist torque which is transfer via CAN. Steering assist torque can help the driver to counter – steer appropriately. It is possible to accelerate to longitudinal by providing suggestive torque to stabilize vehicle

2.2.2 Handling Stability Control

On over-steering or under-steering state, vehicle doesn't moves according to driver's intention. If the driver does not steer appropriately on over-steering or under-steering state, the vehicle can be on dangerous condition as spin out or drift for the worst. Chassis Control System helps to stabilize vehicle and assist driver's maneuver through Steering assist torque. ESC judge vehicle is on over-steering or under-steering condition and decide to do steer intervention for vehicle stability.

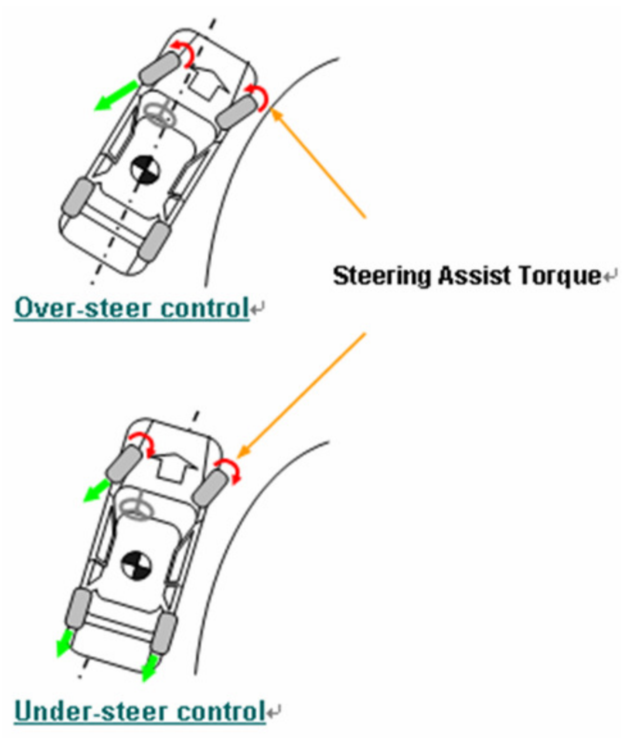


Fig. 7. Handling Stability Control

Steering assist torque is calculated based on delta yaw (difference of yaw rate which is calculated from vehicle model and yaw rate which is measured Yaw Rate sensor). And then Unified Chassis Control System transfers calculated Steering assist torque to EPS System. EPS system generates steering assist torque by motor for vehicle stability. It is most important that Unified Chassis Control is activated not against driver's intention.

3. EXPERIMENT

3.1 Vehicle Test Condition

We performed vehicle test to demonstrate the proposed control strategy improve vehicle stability. The test vehicle was WINSTORM made by GM DAT which is SUV type. Vehicle Test Conditions are as show in Table.1. Test data was estimated by RT 3100.

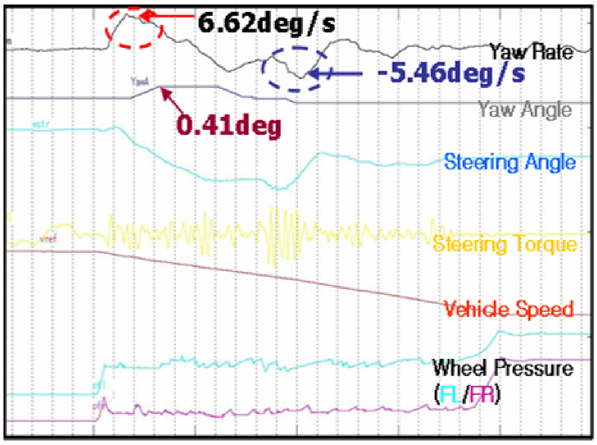
Table. 1. Vehicle Test Conditions

Control Mode	Driving Pattern	Vehicle Speed	Control Specification
Split – μ Braking	- Full Braking - Straight Try	70kph	Peak yaw angle Peak yaw rate
Split – μ Accelerating	- Full Accelerating - Straight Try	0-> 40kph	Peak yaw angle
Handling	Single Sine Wave	80kph	Steering torque increasing

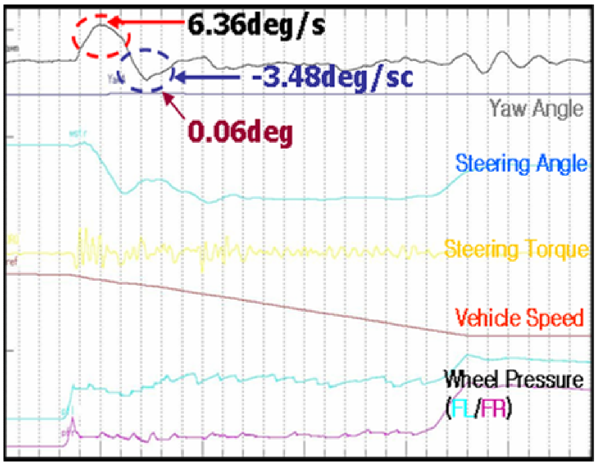
3.2 Split-μ Stability Control

3.2.1 Split-μ Braking Mode

Fig. 8 shows the result of braking on Split - μ road (High-μ on the left side). In this experiment, as show in Table.1, the vehicle is being Braking at a vehicle speed of 70kph on Split - μ roads with steering wheel release. In the case of Individual Chassis Control, as shown Fig. 6(a), Maximum yaw rate is 6.62deg/sec and Minimum yaw rate is -5.46deg/s. Vehicle inclined towards High-μ road.



(a) individual Chassis Control



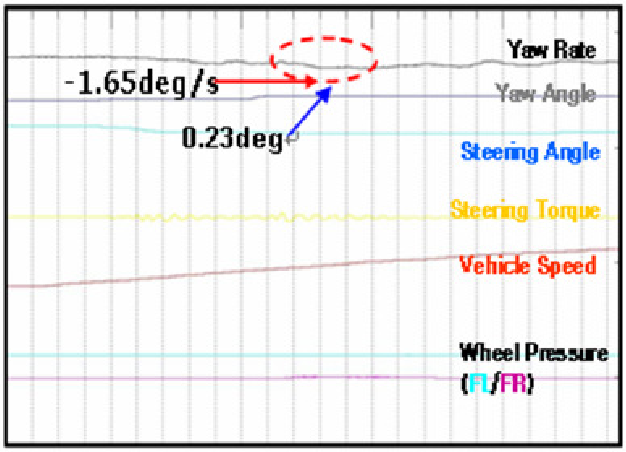
(b) Unified Chassis Contro

Fig. 8. Split-μ Braking Test Results

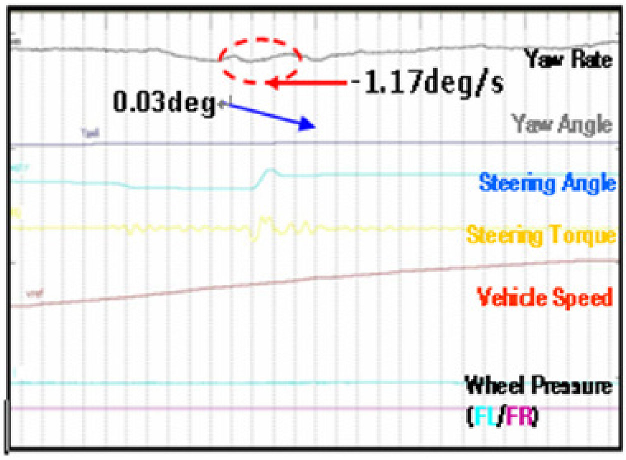
In the case of Unified Chassis Control which generates Steering assist Torque, as shown Fig. 6(b), Maximum yaw rate is 6.36deg/sec and Minimum yaw rate is -3.48deg/s. Maximum yaw angle for Individual Chassis Control is 0.41deg and maximum yaw angle for Unified Chassis Control is 0.06deg. As you see, movement of steer wheel and vehicle state for Unified Chassis Control are more stable than for Individual Chassis Control. The result of test indicated that it is possible to brake to longitudinal direction more stable by steering assist torque of Unified Chassis Control.

3.2.2 Split-µ Accelerating Mode

The result of Accelerating on Split - µ road is showed in Fig. 9. In this experiment, the vehicle is being accelerated up to 40kph on Split - µ roads (High-µ on the right side). In the case of Individual Chassis Control, as shown Fig. 7(a), vehicle is unstable and yaw rate is up to -1.65deg/s which is negative value. In the case of Unified Chassis Control, as shown Fig. 7(b), yaw rate is negative value and it decreases up to -1.17deg/s. Maximum yaw angle for Individual Chassis Control is 0.23deg and maximum yaw angle for Unified Chassis Control is 0.03deg. Result of test indicated that it is possible to accelerate to longitudinal direction with steering wheel release by Unified Chassis Control.



(a) Individual Chassis Control

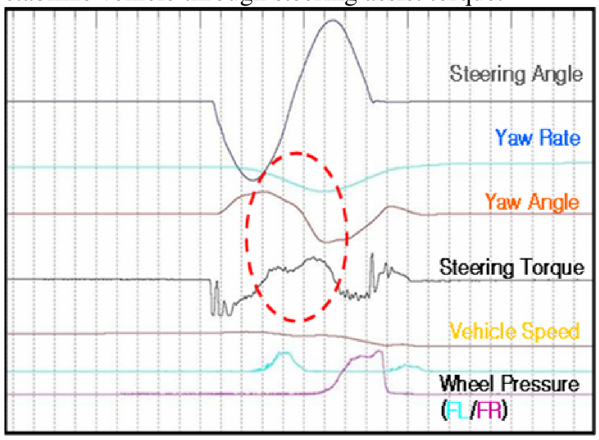


(b) Unified Chassis Control

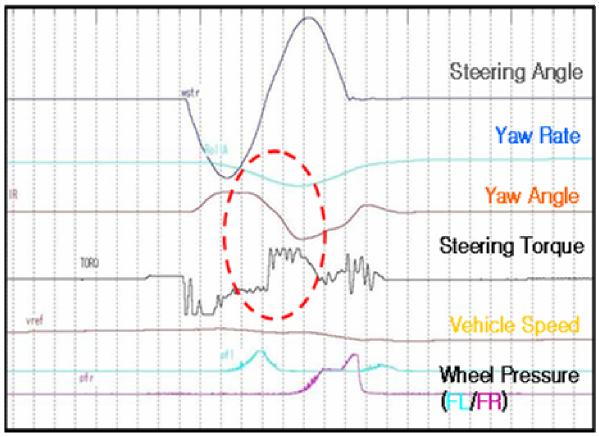
Fig. 9. Split-µ Accelerating Test Results

3.3 *Handling Stability Control*

Fig. 10 shows the results of testing on Single Sine Wave steering as show in Table.1. The vehicle is handled to 175 degree at a vehicle speed of 80Kph on high µ road.
The results presents that the pattern of steering wheel torque between individual Chassis Control and Unified Chassis Control is different. As shown Fig. 7(b), steering assist torque by Unified Chassis Control is activated to assist driver's manuver. Also, Chassis Control System helps to stabilize vehicle through steering assist torque.



(a) Individual Chassis Control



(b) Unified Chassis Control

Fig.10. Single Sine Wave Test Results

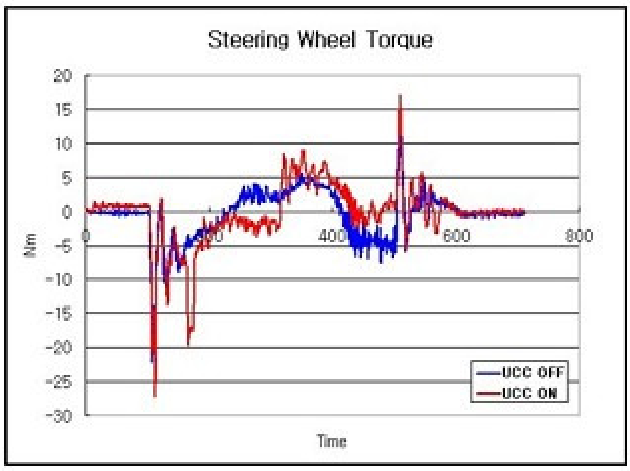


Fig. 11. Steering Wheel Torque

Fig. 11 shows only steering wheel torque of test results of Individual Chassis Control and Unified Chassis Control for Single Sine Wave maneuver on high µ road.

The blue coloured- graph presents steering wheel torque of individual Chassis Control and the red coloured- graph presents steering wheel torque of Unified Chassis Control. On this plot, it shows certain, it is certain difference of the pattern of steering Wheel torque between individual Chassis Control and Unified Chassis Control.

4. CONCLUSION

This paper mentions about Unified Chassis Control system which is consisted of ESC System and EPS System. Unified Chassis Control system improves vehicle stability and steer-ability using steering assist torque generated by motor of EPS system. By compensating the vehicle moment which make vehicle unstable and by assisting driver maneuver through steer intervention, vehicle stability and steer-ability are increased.

We demonstrated the proposed control strategy for Unified Chassis Control System to improve vehicle stability by vehicle test which is braking or accelerating on Split – μ roads and on vehicle under-steer or over-steer condition. On the Split-μ road, Chassis Control System commend steering assist torque to compensate moment of vehicle. On vehicle over-steering or under-steering, Chassis Control System helps driver to steer vehicle by generating steering assist torque.

We are studying for improving robustness and steering feeling for Unified Chassis Control. Also we are developing additional functions of Unified Chassis Control System for production.

REFERENCES

J. H. Jung (2006). “Study on the improvement of yaw stability of the vehicle while braking on the split- road using the unified chassis control", *KSAE*, **Vol 2**, pp776-781.

P.Koehn, M.Eckrich, H.Smarkman, A.Schaffert (2006). “Integrated Chassis Management: Introduction into BMW’s Approach to ICM”, *SAE*, 2006-01-1219

Tanaka H, Kurishige M, Satake T, Kifuku T(2004). “The Torque Controlled Active Steer For EPS”, *AVEC*, pp501~506

Thomas D. Gillespi (1992). *FUNDAMENTALS OF VEHICLE DYNAMICS*, Society of Automotive Engineers Inc

.