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ENHANCEMENT OF VEHICLE STABILITY BY ACTIVE GEOMETRY CONTROL SUSPENSION SYSTEM

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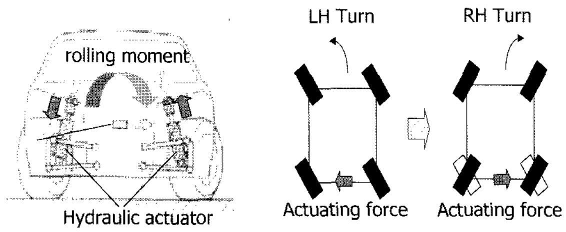
ABSTRACT−This paper presents the enhancement of vehicle stability by active geometry control suspension (AGCS) system as the world-first, unique and patented chassis technology, which has more advantages than the conventional active chassis control systems in terms of the basic concept. The control approach of the conventional systems such as active suspensions (slow active, full active) and four wheel steering (4WS) system is directly to control the same direction with acting load to stabilize vehicle behavior resulting from external inputs, but AGCS controls the cause of vehicle behaviors occurring from vehicle and thus makes the system stable because it works as mechanical system after control action. The effect of AGCS is the remarkable enhancement of avoidance performance in abrupt lane change driving by controlling the rear bump toe geometry.

KEY WORDS : Geometry, Suspension control, Handling, Full-vehicle model

1. INTRODUCTION

In recent years, there has been increased need to develop high-performance suspension for high-power engines, especially active chassis control systems have been developed and mass-produced in the market to compromise vehicle ride and handling performance simultaneously, which are adapted to active, slow active suspension with CDC damper and 4WS system. Especially, it is well-known that 4WS system enhances the high-speed cornering performance by adjusting a rear wheel steer angle (Namio and Junsuke, 1990). However, the conventional active chassis control systems control the vehicle phenomenon such as body roll, yaw, and pitch using hydraulic actuators with the same direction as acting load. So, their hardware and control algorithms are complex and it often happens that cost is high. Figure 1 shows the concept of the conventional active chassis control system. In this paper, AGCS control concept has been introduced and its performances were analyzed with the ADAMS full vehicle model. The simulation results of AGCS system show the improved handling performance. In addition, the subjective tests were performed to evaluate the AGCS performance for lane change and steady-state cornering.



(a) Slow active suspension (b) 4WS

Figure 1. Concept of the conventional active chassis control system.

2. AGCS OVERVIEW

The kinematics arrangement of the suspension link changes toe angle, which is largely affecting running stability, as the running condition changes. The AGCS system of Hyundai Motors is a device to optimize the toe angle of a rear wheel by controlling the position of a rear suspension link. Figure 2 shows the comparison between the conventional active chassis control system and AGCS system. It consists of actuators, control lever (these are mounted in rear subframe) and ECU as shown in Figure 3. ECU is adjusting actuator stroke based on the vehicle speed and steering angle. Then the control lever is rotating downward or upward around hinge. It moves the inboard mounting point of the rear wheel assist link to maintain optimal bump toe-in value.

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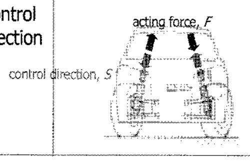
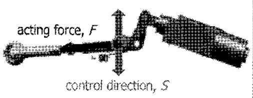
Item	Conventional active chassis system	AGCS
Control concept	Control the phenomenon	Control the cause of the phenomenon
Control direction	Same direction with acting load → large energy W = F • S = |F||S|cos(0) = |F||S| 	Perpendicular direction with acting load → Small energy W = F • S = |F||S|cos(90°) = 0 

Figure 2. Comparison between the conventional active chassis control system and AGCS (Lee, 1994; 1996; 2001).

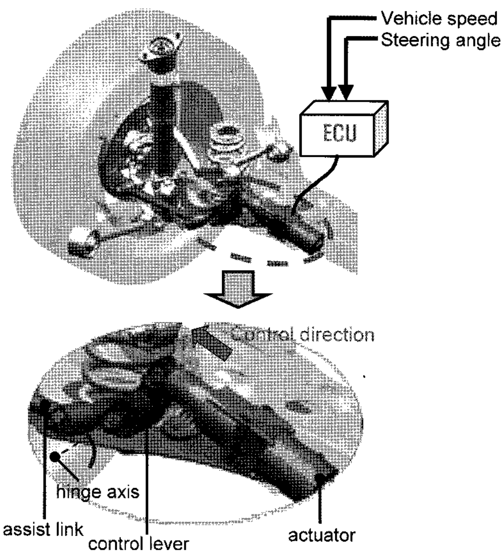


Figure 3. AGCS system layout.

Sensor part has vehicle speed sensor and steering angle sensor. Vehicle speed sensor reads the vehicle's speed, and the steering angle sensor reads the driver's steering amount. Control part commands the actuator by estimating lateral acceleration acting on the vehicle based on the data from the vehicle speed sensor and the steering angle sensor. Actuator part is producing the optimal toe angle of the rear outside wheel by controlling the position of the link mounting point of rear wheel based on the command from the control part.

The concept of AGCS is intelligent, and it overcomes many negative points of conventional active suspension systems. AGCS has simple control logic and hardware equipment. Moreover, if energy supply goes off in conventional system the performance becomes failure mode but in AGCS, vehicle performance will be equal to passive suspension.

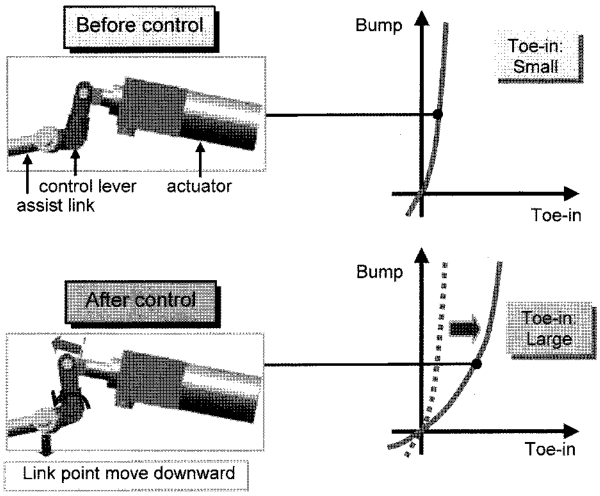


Figure 4. Bump toe characteristics.

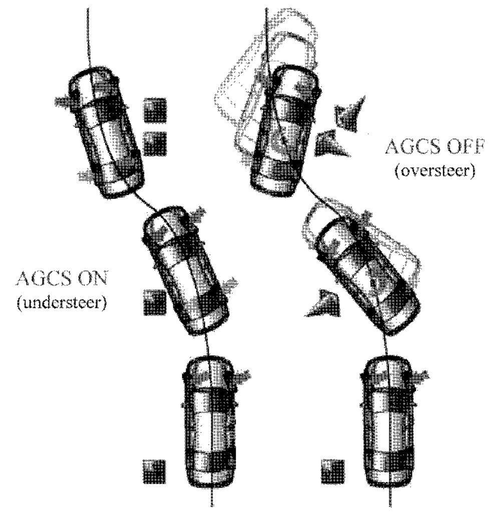


Figure 5. Vehicle trajectory in high-speed cornering.

At situations accompanying rolling such as high speed cornering the equal to passive suspension. At situations accompanying rolling such as high speed cornering the AGCS system estimates lateral acceleration acting on the vehicle based on the data from vehicle speed sensor and steering angle sensor.

Based on the estimated lateral acceleration, it moves the actuator to increase rear outside (Figure 4).

Since abrupt steering at high speed produces large centrifugal force on the vehicle, the rear part of the vehicle slips outward (AGCS OFF in Figure 5).

Thus, it is difficult for the vehicle to show stabilized steering performance. The AGCS system prevents the vehicle from leaning, which increases grip force of the rear wheels, thereby decreasing the rear-sway (AGCS ON in Figure 5).

3. CONTROL LOGIC

The control logic of the AGCS system is investigated in this section. The objective of the logic philosophy was to maximize the positive effect of the AGCS on the precise situations. The most important aims to accomplish are:

- Actuation starting points at constant levels of lateral acceleration for all speeds in order to guarantee homogenous effect
- Definition of different control maps with increasing AGCS application strokes with increasing lateral acceleration levels for better progressivity and natural effect on the handling response of the vehicle

The definition of all the logic has been done bearing in mind the control parameters available for the set-up:

- Vehicle speed
- Steering wheel angle
- Steering wheel rate (actually this value is calculated)

Only an additional throttle position has been used for the consideration of the power-off in turn situation.

The idea to be applied in the control logic is to establish the starting point of the actuation of the AGCS at a certain level of lateral acceleration of the vehicle. This level will be determined based on the steady-state characteristics of the vehicle for different speeds, therefore with a given steering wheel angle and speed the system will establish the corresponding steady state acceleration and decide the actuation of the AGCS. Additionally different mappings will be defined based on the steering wheel angle rate.

This will inform about the level of non-steady state (or transient) situation of every driving condition of the vehicle. The more transient the situation will be the sooner and the more aggressive the system will act on the suspension. Figure 6 shows the control logic flow of the AGCS system.

4. SIMULATION AND TEST RESULTS

In this section, in order to verify the effectiveness of AGCS the step steer input simulation is performed using full vehicle ADAMS model (Mechanical Dynamics Inc, 2002). The vehicle model comprises double wishbone front suspension and multi-link rear suspension (Figure 7). The AGCS ADAMS model consists of assist link,

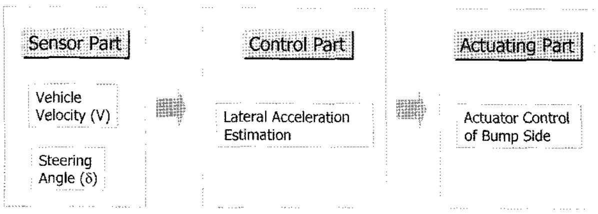


Figure 6. Control logic flow.

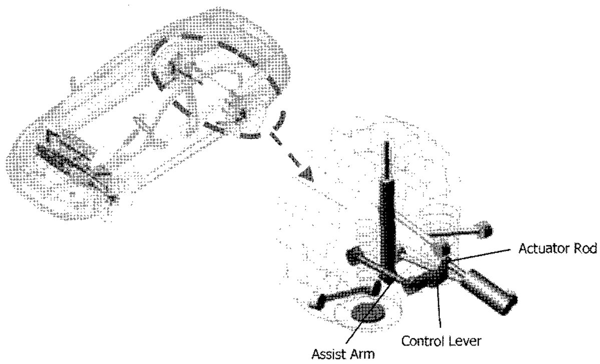


Figure 7. Full vehicle model (ADAMS).

control lever and actuator. Control lever is connected to the assist link with the bushing and also connected to the subframe by the revolute joint. The connecting part between the actuator and the control lever is modeled with a contact element of ADAMS. As the actuator generates translational motion, the control lever will rotate about the revolute joint, and assist link mounting point moves downward.

4.1. Step Steer Input Simulation

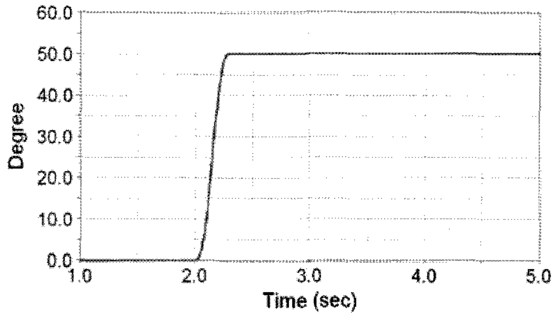
Step steer input maneuver is simulated to investigate the transient response in AGCS OFF and ON condition. Vehicle speed is 140 KPH and steering wheel angle is 50 degrees. Figure 8 shows the results of vehicle response for the step steer input. It can be noted that the overall trends in AGCS ON condition have superior performance when compared to those in AGCS OFF condition. Especially, in case of maximum magnitudes of body side slip angle are considerably reduced in AGCS ON condition (Table 1).

4.2. Sinusoidal Input Simulation

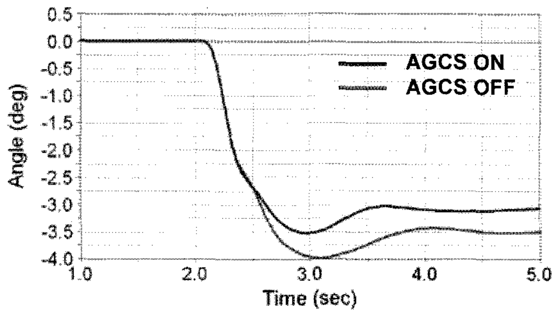
Also, the sinusoidal input maneuver is performed to investigate the transient handling performance. Initial vehicle speed is 140 KPH and steering wheel angle is sinusoidal as in Figure 9(a). Figure 9(b)–(d) show the results of transient response for the sinusoidal input. Like the step steer input, it can be noticed that AGCS ON vehicle has superior handling performance than AGCS OFF vehicle. In particular, it can be found that magnitude reduction of side slip angle is large in case AGCS ON condition (refer to Table 2).

4.3. Subjective Test

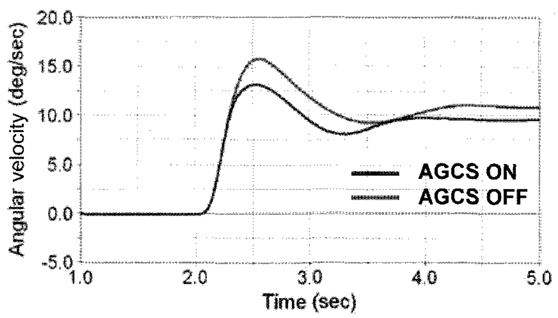
In order to establish the level of influence of the AGCS effect, The rear suspension were installed with AGCS hardware such as actuator, control lever for road testing in Figure 10 (ECU is not seen in the Figure). The subjective evaluations are performed to cover the principal aspects of the handling performance that are affected by



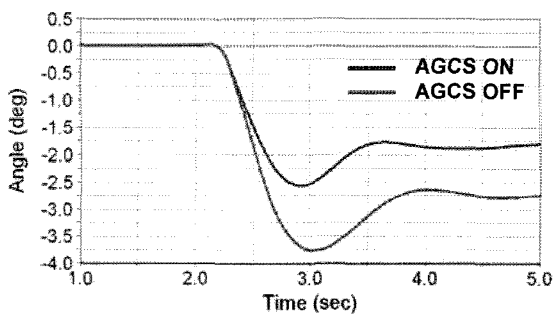
(a) Steering angle



(b) Roll angle



(c) Yaw rate



(d) Body side slip angle

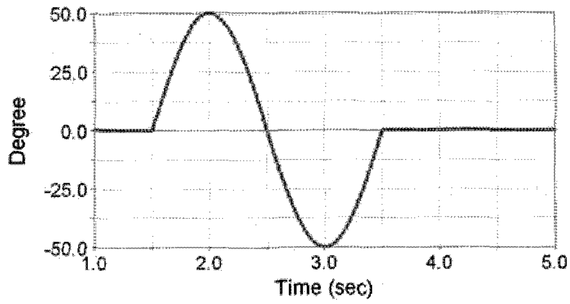
Figure 8. Step steer input simulation results.

AGCS system. Test driver tries two kinds of driving case, AGCS off and on condition for single lane change and quasi steady-state cornering.

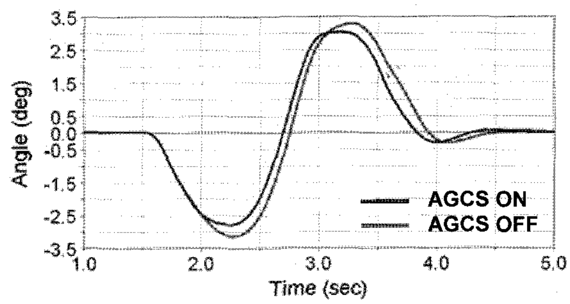
The vehicle characteristics are also evaluated when turning in steady-state or quasi steady-state situation. All

Table 1. Maximum magnitudes comparison in step steer input simulation.

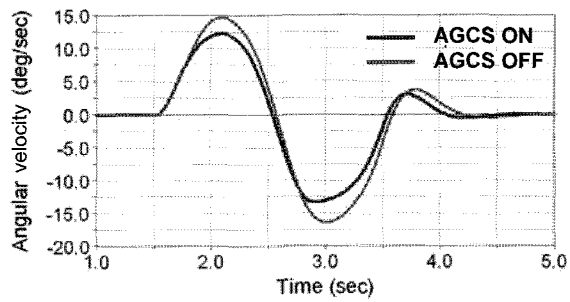
Item	AGCS off	AGCS on
Roll angle	−3.99 deg	−3.58 deg (10.3%↓)
Yaw rate	15.79 deg/s	14.52 deg/s (8.0%↓)
Side slip angle	−3.77 deg	−2.7 deg (28.43%↓)



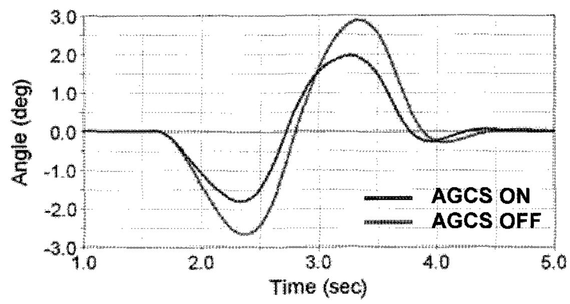
(a) Steering angle



(b) Roll angle



(c) Yaw rate



(d) Body side slip angle

Figure 9. Sinusoidal input simulation results.

Table 2. Maximum magnitudes comparison in sinusoidal input simulation.

Item	AGCS off	AGCS on (reduction %)
Roll angle	3.29 deg	3.03 deg (7.9%↓)
Yaw rate	−16.38 deg/s	−13.29 deg/s (18.0%↓)
Side slip angle	2.88 deg	1.95 deg (32.29%↓)

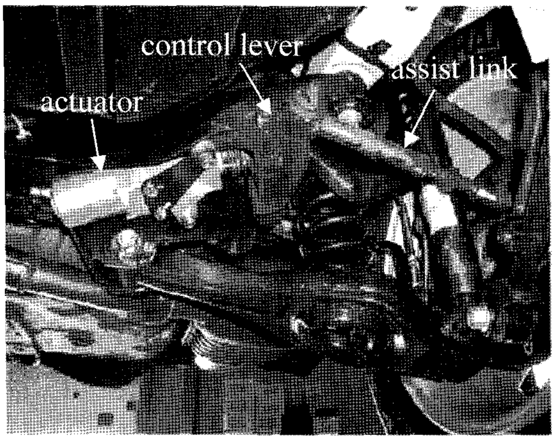


Figure 10. AGCS hardware mounted on the test car (rear suspension).

the response properties and balance of the vehicle is marked. The punctuation of the different points is from 1–10, and target as follow;

Rabing	~3	4	5	6	7	8	9	10
Perception	Poor	Objection	Requires improvement	Barely acceptable	Fair	Good	Very good	Excellent

The summary table with all evaluations is shown in Table 3.

Vehicle response during lane change is rather good at low-mid levels of lateral accelerations, delay, damping and response (roll a bit excessive, lack of damping). However, at higher lateral accelerations the poor yaw damping and excessive vehicle reaction makes the response too quick and difficult to control. Oversteer occurs at the limit and countersteer is necessary.

The vehicle with AGCS improves the transient reaction by increasing the yaw damping as the most important effect. Additionally some other improvements are also noticed like faster reaction of the car, and more progressive and understeer response.

Steady-state response is rather good with a understeering evolution. Predictability of limit is rather good, but increasing understeering would improve it.

The influence of AGCS is only reached when steering wheel inputs are higher than certain degrees. This is not a purely steady-state situation but could be considered as a slight transient and include it on this evaluation. The effect of AGCS is small, but in the right direction. The generation of rear slip is more controlled and the understeering tendency at the limit of adherence more pronounced. The results in a better predictability of grip limit, and improved balance of front and rear slips.

Table 3. Subjective ratings comparison (Català, 2004).

Test item	Performance	AGCS off	AGCS on
Lane change	Response damping	6	7.5
	Rear slip generation	6.5	7.7
	Controllability at the limit	6.5	6.9
Quasi steady-state comening	Understeering tendency	6.5	7
	Front-rear balance	6.7	7.5
	Predictability of limit	7	7.2

5. CONCLUSIONS

In this paper, AGCS to improve handling performance as the active chassis control system is suggested. The summaries of results are as follows:

(1) The AGCS system is applied on the rear suspension to regulate bump toe-in using the electric actuator which varies the geometry of assist link, and enables to improve road grip and extend the slipping point.
(2) Because the control direction is perpendicular to the acting load in regulating wheel toe-in, the system is inherently more efficient than conventional systems that control in the same direction as the acting load.
(3) AGCS system has superior handling performance when compared to the conventional system in step input simulation results and subjective tests.

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