Development of Integrated Vehicle Dynamics Control System 'S-AWC'

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Abstract

The Super All Wheel Control (S-AWC) for LANCER EVOLUTION X is an integrated vehicle dynamics control system for handling the Active Center Differential (ACD), Active Yaw Control (AYC), Active Stability Control (ASC) and Antilock Brake System (ABS). It is based on the All Wheel Control (AWC) philosophy advocated by Mitsubishi Motors Corporation (MMC). To ensure predictable handling and a high performance margin, the S-AWC system calculates the yaw moment by using the yaw rate feedback control and distributes the yaw moment to each component taking into consideration its characteristics. S-AWC can improve the vehicle cornering performance seamlessly at various driving conditions.

Key words: *Four Wheel Drive (4WD), Vehicle Dynamics, Integrated Control*

1. Introduction

The All Wheel Control (AWC) is a MMC's four-wheel dynamic control philosophy for maximally exploiting the capability of all four tires of a vehicle in a balanced manner to realize predictable handling and high margin of performance, which in turn yield the driving pleasure and utmost safety that MMC sees as fundamentals in producing vehicles.

The Super All Wheel Control (S-AWC) is an integrated vehicle dynamics control system that combines various components based on the four-wheel drive (4WD) control, and controls all components integrally to embody the AWC philosophy(1).

The S-AWC system on the LANCER EVOLUTION X delivers all of the following functions under integrated control: Active Center Differential (ACD)(2), Active Yaw Control (AYC)(3), Active Stability Control (ASC)(4), and Antilock Brake System (ABS). As shown in **Fig. 1**, by adding braking control to the ACD-AYC combination, which has superior controllability among the currently existing 4WD systems, the S-AWC can control both the driving and braking forces and so handle both longitudinal and lateral behavior of the vehicle. As a result, the S-AWC seamlessly improves the vehicle's dynamic performance for various vehicle operations such as acceleration, deceleration and cornering.

This paper introduces the S-AWC system focusing on the integrated driving and braking force control using the yaw rate feedback control technology, which is the most remarkable feature of the system.

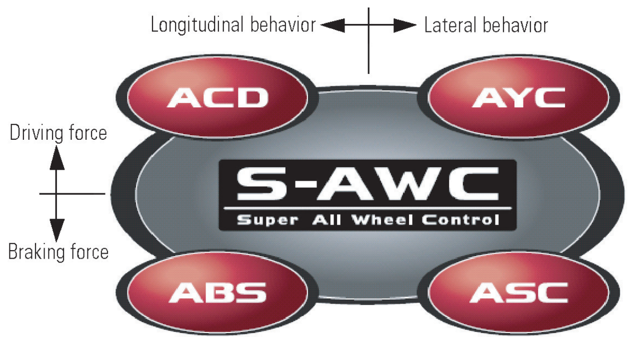

Fig. 1 Components of S-AWC

2. Consideration and selection of system configuration

2.1 Basic control method

The aim of the S-AWC system is to achieve both predictable handling and high margin of performance.

Predictable handling means changing the vehicle direction faithfully according to the driver's intentions, in other words, the vehicle exactly follows the driver's steering operations. High margin of performance, on the other hand, means keeping the vehicle direction without being affected by disturbances, in other words, restraining vehicle's behavioral changes that are not caused by the driver's steering operations.

Although these two characteristics appear different, they are similar in that they both require the vehicle's behavior to match the driver's steering operation, and can be achieved simultaneously by minimizing the difference between the target vehicle behavior calculated from the steering wheel angle and the actual vehicle behavior.

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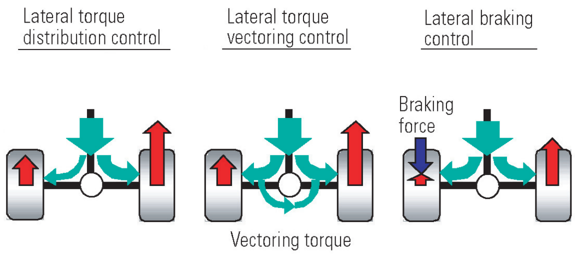

Fig. 2 Various types of direct yaw moment control

To achieve this, the S-AWC system adopts yaw rate feedback control as basic control method, in which the vehicle behavior (target yaw rate) calculated from such parameters as the steering wheel angle is compared with the actual vehicle behavior (actual yaw rate) given by the yaw rate sensor to determine the target amount of control to be provided by the system.

2.2 Components

To make the yaw rate feedback control work effectively, it is necessary to control the yaw moment acting on the vehicle most appropriately under various driving conditions.

The types of control that can generate yaw moment include the following: the steering angle control working on the steering system; the roll stiffness distribution control working on the suspension system; the longitudinal torque distribution control and the lateral torque difference control working on the drive train; and the lateral braking control. The steering angle control can effectively generate yaw moment in the linear region of the tire characteristics, but it cannot generate sufficient moment in the nonlinear region of the tire characteristics. The roll stiffness distribution control can indirectly control the yaw moment, but its effect is limited to the nonlinear region of the tire characteristics. Similarly, the longitudinal torque distribution control is effective only in the nonlinear region of the tire characteristics. On the other hand, the direct yaw moment control that uses the difference in driving and braking forces between the left and right wheels can generate yaw moment in both the linear and nonlinear regions of the tire characteristics(5).

There are three types of direct yaw moment control technology currently available, as shown in **Fig. 2**.

The lateral torque distribution control unequally distributes the engine torque to the left and right wheels. The resulting difference in driving torque between the left and right wheels generates the yaw moment. This control, therefore, cannot effectively generate the yaw moment during cruising or deceleration when the engine torque is not large enough.

The lateral torque vectoring control transfers the torque from the left wheel to the right wheel, and vice versa, to generate an amount of braking torque on one wheel while generating the same amount of driving torque on the other wheel. The control of this type, therefore, can generate the yaw moment at any time regardless of the engine torque. Another merit of this control is that it does not affect the total driving and braking forces acting on the vehicle, which means that the control does not conflict with acceleration and deceleration operations by the driver. Although this control affects the steering reaction force when applied to the front wheels, it does not produce any adverse effects when applied to the rear wheels.

The lateral braking control applies different braking forces to the four wheels independently so as to produce a difference in braking force between the left and right wheels, which generates the yaw moment. As this control uses braking forces, it feels to the driver like deceleration, but the control is effective because it can generate yaw moment under a wide range of conditions of vehicle operation.

In view of the characteristics of these three yaw moment control technologies, a combination of the lateral torque vectoring control applied to the rear wheels and the lateral braking control is the most effective way of providing the yaw rate feedback control seamlessly under varying vehicle driving conditions from acceleration to deceleration. The AYC differential introduced by MMC to its products in 1996 is the world’s first component to use lateral torque vectoring control. The braking control can be achieved by using ASC or other existing brake control systems.

For the reasons mentioned above, the S-AWC system consists of ACD, AYC, ASC, and ABS. This configuration is based on the LANCER EVOLUTION IX’s system to which the braking control system is added.

3. Configuration and features

Fig. 3 shows the general configuration of the S-AWC system installed into the LANCER EVOLUTION X.

The system has the S-AWC controller, which acts as the master controller. It controls the ACD transfer (longitudinal differential limiting control), AYC differential (lateral torque vectoring control), and brakes integrally by giving commands to the ACD/AYC hydraulic unit and ASC/ABS unit.

For communications between the S-AWC controller and ASC/ABS unit, an independent controller area network (CAN) is used to be able to process large amounts of information at high speed. In addition, the ASC/ABS unit incorporates brake pressure sensors for each of the four wheels and linear valves to ensure smooth and accurate braking control. These ensure precise and highly responsive integrated control.

In addition to the sensors used in the LANCER EVOLUTION IX (steering wheel angle sensor, longitudinal acceleration sensor, lateral acceleration sensor, wheel speed sensors for four wheels, accelerator position sensor, etc.), the yaw rate sensor (integrated yaw and G sensor) is adopted for providing information for yaw rate feedback control. Another feature of the system is the additional sources for such information as the engine torque, engine speed and brake pressure, which all allow the vehicle acceleration and deceleration states

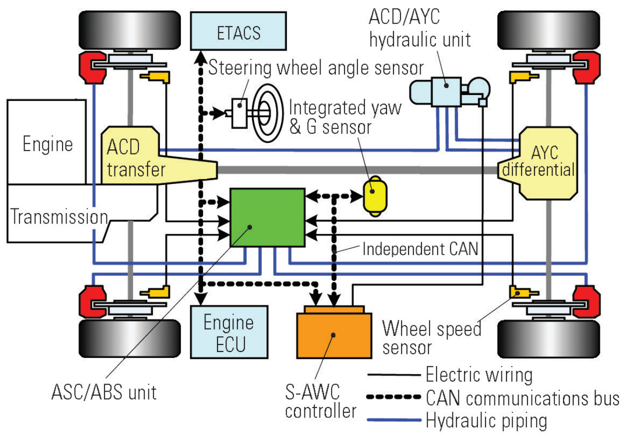

Fig. 3 System configuration

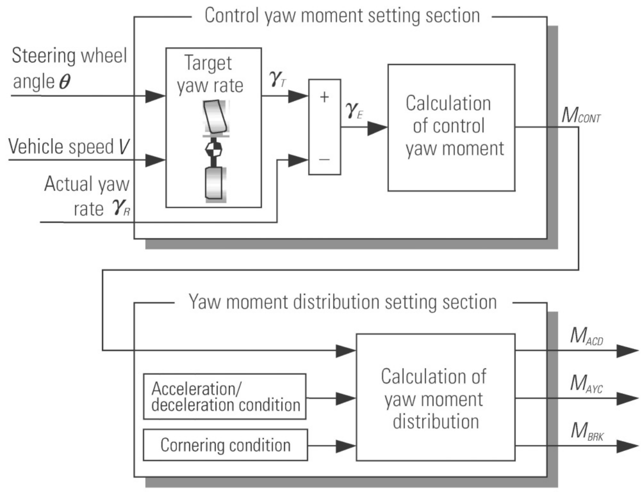

Fig. 4 Control diagram

Table 1 Comparison of component characteristics

		In improving cornering	In restraining cornering
During acceleration	Longitudinal differential limiting control	–	★
	Lateral torque vectoring control	★★★	★★
	Braking control	★	★
During deceleration	Longitudinal differential limiting control	–	★
	Lateral torque vectoring control	★★	★
	Braking control	★★	★★★

★: Control effect

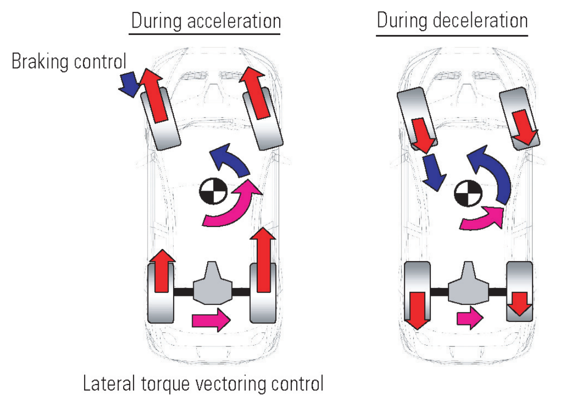

Fig. 5 Yaw moment distribution in improving cornering

to be quickly and accurately identified, and thus for the control response to be improved.

4. Outview of system control

Table 1 summarizes the characteristics of the longitudinal differential limiting control, lateral torque vectoring control, and braking control. The longitudinal differential limiting control has a stabilizing effect on the vehicle when it is likely to spin, in other words, it can restrain cornering. The lateral torque vectoring control works effectively during acceleration, when loads on the rear wheels increase. It is most effective in improving cornering when the torque is transferred to the outer wheels, on which the load increases. The braking control is most effective in restraining cornering during deceleration where it can provide control effects without causing the driver to perceive excessive deceleration. Seamless and high-quality yaw moment control can be achieved by appropriately combining these control effects based on their characteristics. The control logic shown in **Fig. 4** is designed in line with this concept.

The control yaw moment setting section in the figure uses a linear two-wheel model to calculate the target yaw rate γ_T from the steering wheel angle θ and vehicle speed V, and the control yaw moment M_{CONT} to be applied to the vehicle is determined based on the difference γ_E of the target yaw rate γ_T and the actual yaw rate γ_R.

The yaw moment distribution setting section, on the other hand, apportions the control yaw moment M_{CONT} among the longitudinal differential limiting control yaw moment M_{ACD}, lateral torque vectoring control yaw moment M_{AYC}, and the braking control yaw moment M_{BRK} according to the condition of acceleration, deceleration and cornering. For example, when the vehicle's cornering motion is improved, the section increases the distribution of yaw moment to the lateral torque vectoring control during acceleration, whereas it increases the distribution of yaw moment to the braking control during deceleration (**Fig. 5**). When the vehicle's cornering motion is restrained, on the other hand, the section first increases the distribution of yaw moment to the braking control and then to the longitudinal differential lim-

Fig. 6 Result of sporty driving on dry handling circuit

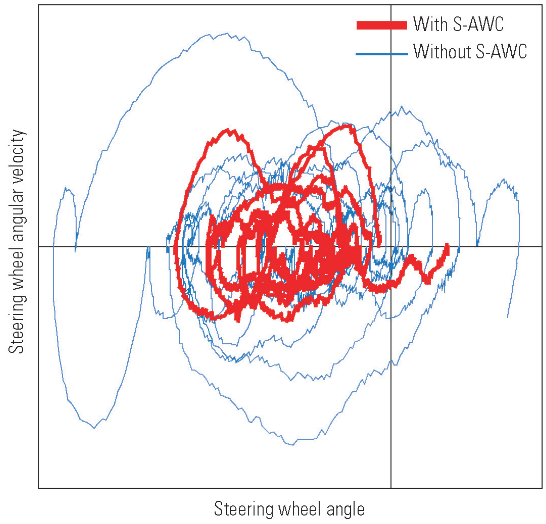

Fig. 7 Result of cornering on a snow packed road

iting control.

Like this example, the system achieves an integrated vehicle dynamics control using the yaw rate feedback by apportioning the yaw moment among the longitudinal differential limiting control, left-right torque vectoring control and the braking control most appropriately according to the characteristics listed in **Table 1.**

5. Vehicle performance

This section describes how the S-AWC demonstrates its effect in an actual vehicle using an example. This example compares the dynamics control results derived from the tests on the same vehicle when it is equipped with the S-AWC (called "With S-AWC" hereafter) and when it is equipped with a control system that simulates the LANCER EVOLUTION IX's system (called "Without S-AWC").

Fig. 6 shows the steering wheel angles and the steering wheel angular velocities plotted on the same graph for when the vehicle was put in sporty driving on a 2.4-km dry handling circuit. It shows that the With S-AWC presented smaller values for both the steering wheel angle and steering wheel angular velocity and that the lap time of the With S-AWC was about 1.5 seconds shorter than the Without S-AWC.

Fig. 7 shows the steering wheel angles and steering wheel angular velocities plotted on the same graph for when the vehicle was turned around a 15-m radius circle as fast as possible on a snow packed road. It shows that the With S-AWC presented substantially smaller values in both the steering wheel angles and steering wheel angular velocities than the Without S-AWC.

These test results clearly show that the S-AWC improves the vehicle's response to operation of the steering wheel regardless of the road surface conditions and helps drive the vehicle reliably at faster speeds with less operation of the steering wheel. In other words, the S-AWC system improves the cornering performance, stability and controllability of the vehicle.

6. Conclusion

With the integrated vehicle dynamics control capability realized using the yaw rate feedback control as the base technology, the S-AWC system on the LANCER EVOLUTION X has succeeded in dramatically improving the vehicle dynamics performance under various driving conditions, thereby achieving both predictable handling and high margin of performance.

MMC will continue to evolve the S-AWC system by adding novel components and improving the control logic, aiming to improve the dynamics performance of our products even further.

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