

Enhancements in Handling on Slippery Roads with VSA

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ABSTRACT

The performance of Vehicle Stability Assist VSA was tested for reproducibility under various conditions encountered on slippery roads. The results showed that VSA enhances stability and steerability, that driver fatigue was reduced, and collision avoidance performance was enhanced. This thus demonstrated the effectiveness of VSA.

1. Introduction

The authors previously reported on enhancements to stability and steerability made through research into VSA with 4-wheel optimum slip control⁽¹⁾. In this new research project they have performed vehicle handling verifications using VSA on ice- and snow-covered roads. The results confirm that there is an enhancement in vehicle stability and steerability under the snow and ice conditions encountered on these slippery road surfaces. Further, the authors confirmed that VSA with 4-wheel slip control is effective in reducing the likelihood of collisions where the vehicle over-steers or leaves the lane. The test vehicle used was an FF (front engine, front drive) vehicle with on-demand type 4-wheel-drive, and the test course was a snow- and ice-covered road surface.

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2. Test Modes

In cold or snowy regions, one may encounter numerous situations where handling instability may occur. Examples of these situations include driving at an excessive speed leading to the vehicle being unable to trace a corner; seeing an obstacle and braking suddenly while turning; sudden steering to avoid something that jumps out onto the road; or, an operating error due to the fatigue and stress of driving on winding roads. From these scenarios, the following four test modes were established.

- (1) J-turn (approaching a corner at excessive speeds)
- (2) Braking in turn (sudden braking while turning)
- (3) Double lane change (collision avoidance rapid steering)
- (4) Continuous slalom (driving on winding roads)

VSA performance, in terms of both stability and

steerability, was evaluated in each of these situations.

That is, the purpose of this research project was to verify, using an actual vehicle, the achievement of both of the following:

- (1) Reduction of driver fatigue due to stability enhancements: Stability (rear tire grip)
- (2) Enhanced collision avoidance performance: Steerability (steering effectiveness)

3. Control Logic

VSA is composed of three basic control logics:

- (1) Vehicle side slip angle estimation logic (β estimation logic)
- (2) Tire and road friction coefficient estimation logic (μ estimation logic)
- (3) Optimum 4-wheel slip control logic (λ control logic)

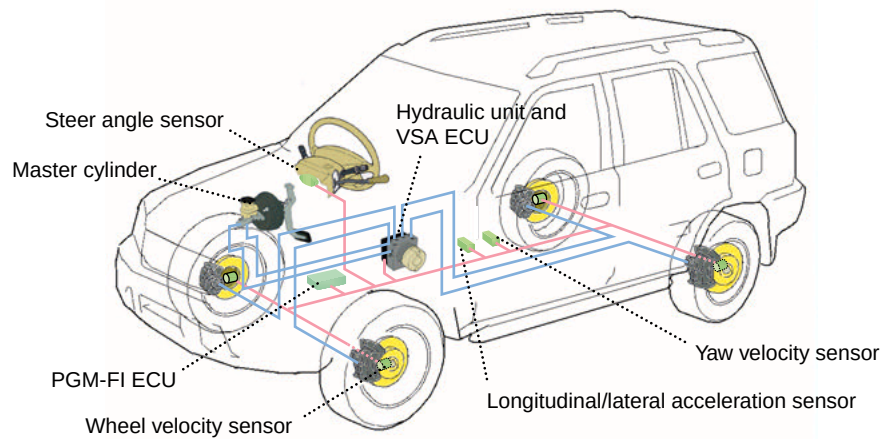


Fig. 1 System configuration

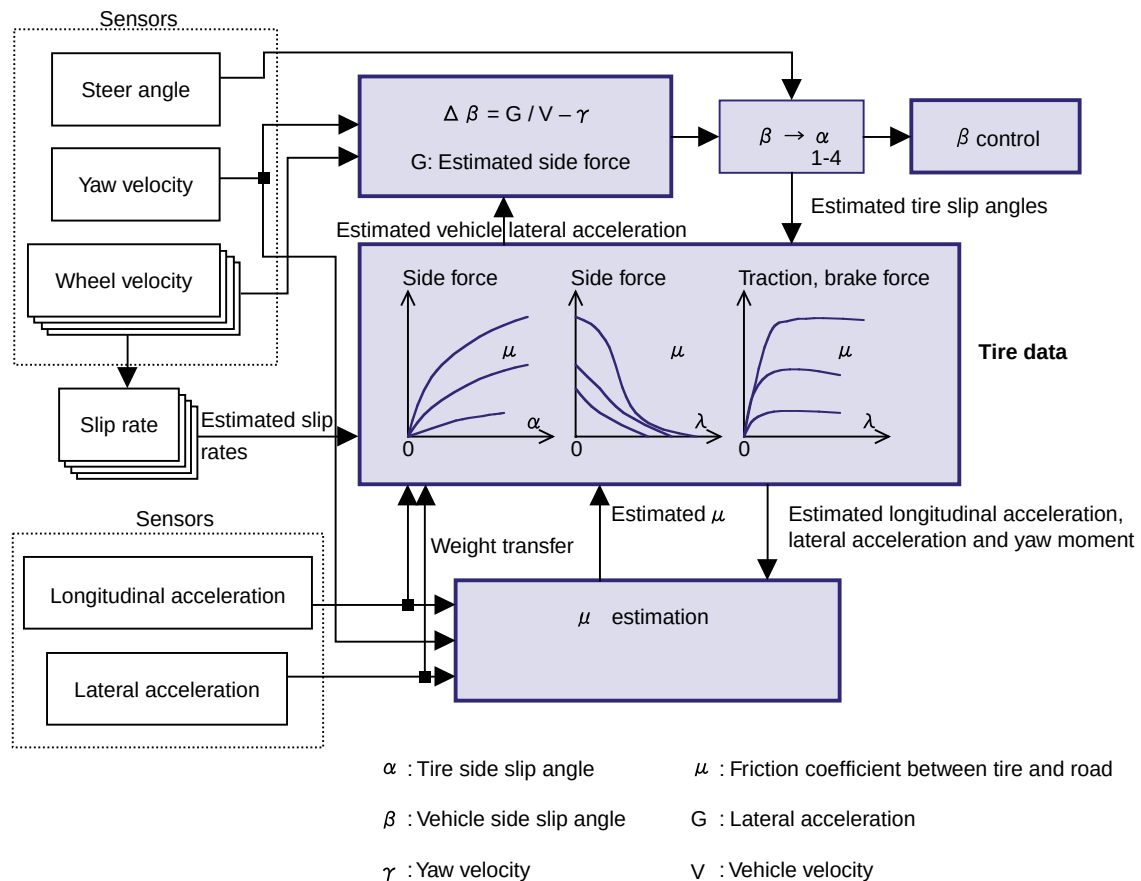


Fig. 2 Basic VSA logic

This project achieved enhanced performance on snow- and ice-covered roads by modifying the following three VSA control logics:

- (1) Vehicle speed estimation logic
- (2) Under-steer control logic
- (3) Over-steer control logic

The basic configuration of the VSA control system is shown in Fig. 1. The basic control logics are shown in Fig. 2. The three control logics the team worked on to enhance performance on snow and ice are described below.

3.1 Vehicle Speed Estimation Logic

In order to increase vehicle speed estimation accuracy during start-slip control, low μ split driving, or slip control operation, vehicle speed is determined by converting total brake and traction forces for each tire, which is estimated from slip- μ characteristics (tire map data), into estimated longitudinal acceleration, as shown in Fig. 3. Also, tire characteristics are adapted to fit the μ estimation logic.

3.2 Under-steer Control Logic

Under-steer (US) generally occurs when entering a corner at excessive speeds, as shown in Fig. 4. Thus, rear wheel brake control and front inner wheel moment control are activated simultaneously for 3-wheel control. In particular, as for rear tires, a brake force difference is applied to the left and right wheels after deceleration so that a proper moment is generated.

3.3 Over-steer Control Logic

A moment restricting control that operates at an earlier stage has been developed to help control over-steer (OS). This control works to help prevent the sudden yaw moment arising from rapid left and right continuous steering during an emergency avoidance maneuver, and also considers the comparatively heavy inertial moment of an SUV. In practical terms, as shown in Fig. 5, excess moment is estimated and controlled when (1) the vehicle side slip angle exceeds the threshold, and then (2) the yaw rate changes from a negative to a positive value, or vice versa.

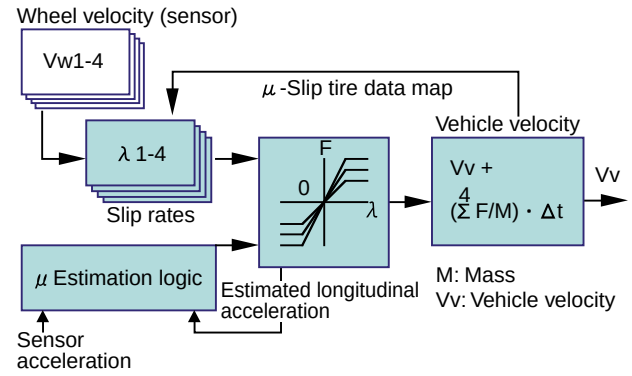


Fig. 3 Vehicle velocity estimation logic

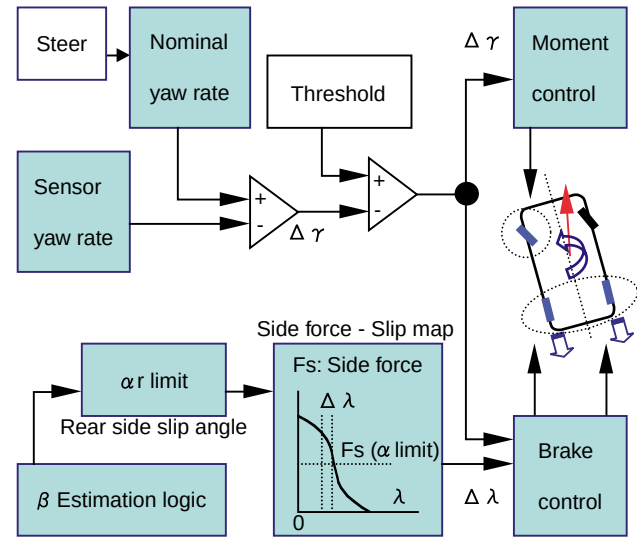


Fig. 4 Under-steer control logic

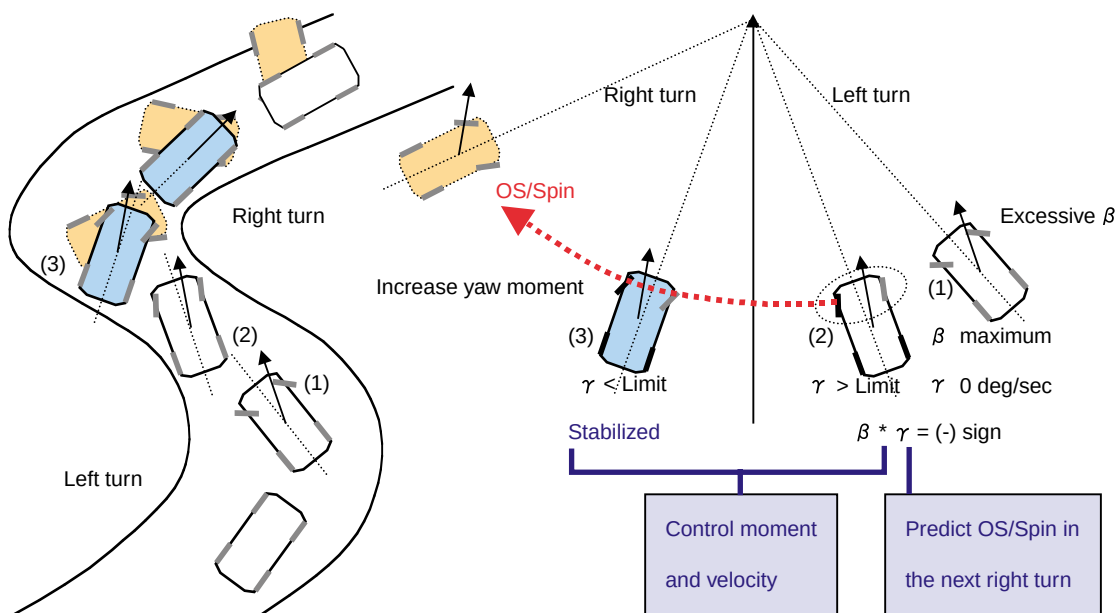


Fig. 5 Prediction and control for excessive yaw moment on the slalom course

4. Test Results

4.1 50R J-turn Test (entering corner at excessive speeds)

The test mode and images of a vehicle driving on the test course are shown in Fig. 6.

Fig. 7 shows the tire grip limits are exceeded, and the

vehicle diverges outward from the target course when VSA is not in operation. In contrast, when VSA does operate, as shown in Fig. 8, the vehicle divergence from the target line is kept to a minimum, and stability and steerability are generally maintained. This is due to the operation of rear wheel deceleration control and front inner wheel moment control.

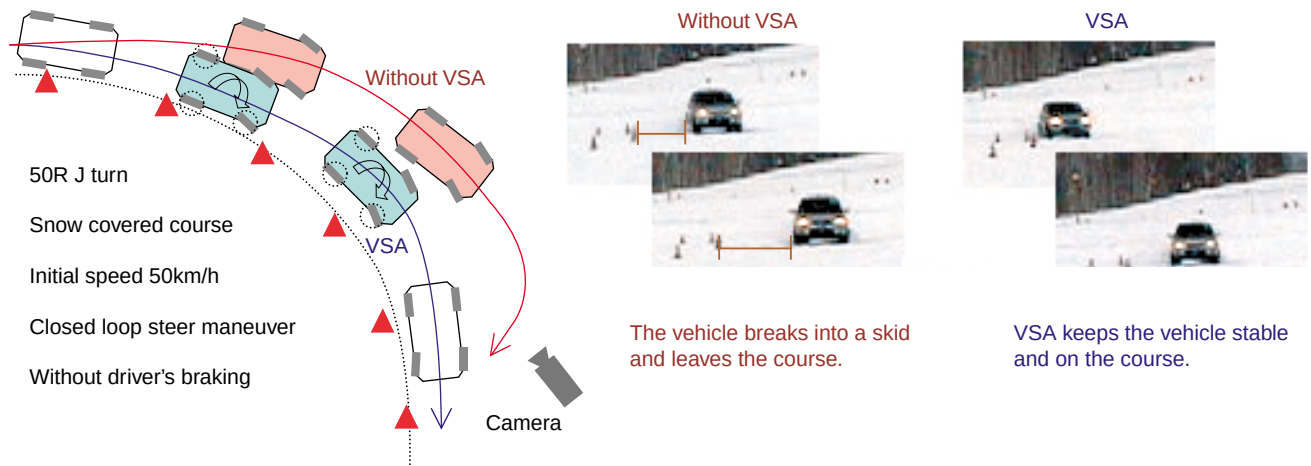


Fig. 6 50R J turn test

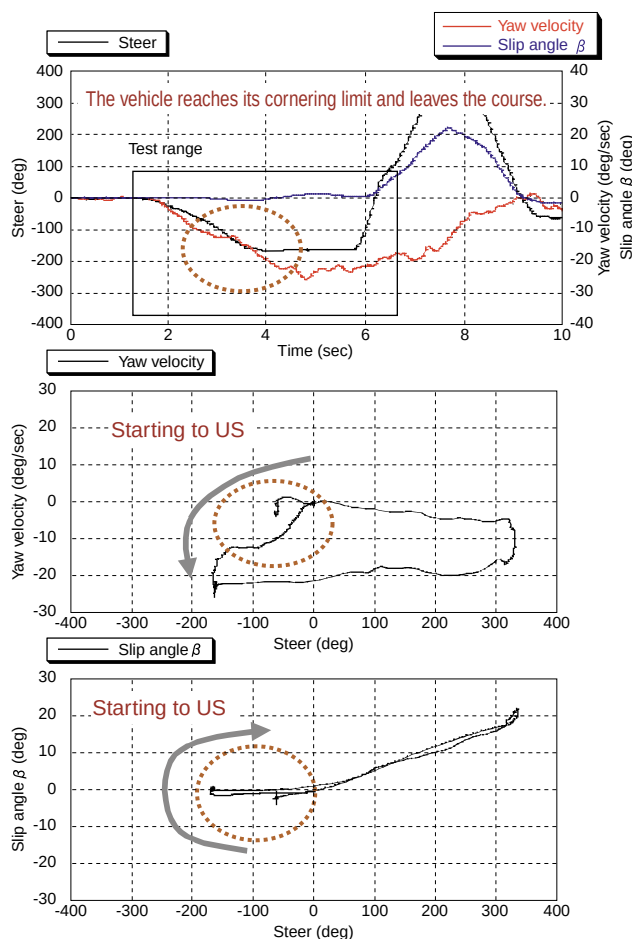


Fig. 7 50R J turn test on snow without VSA

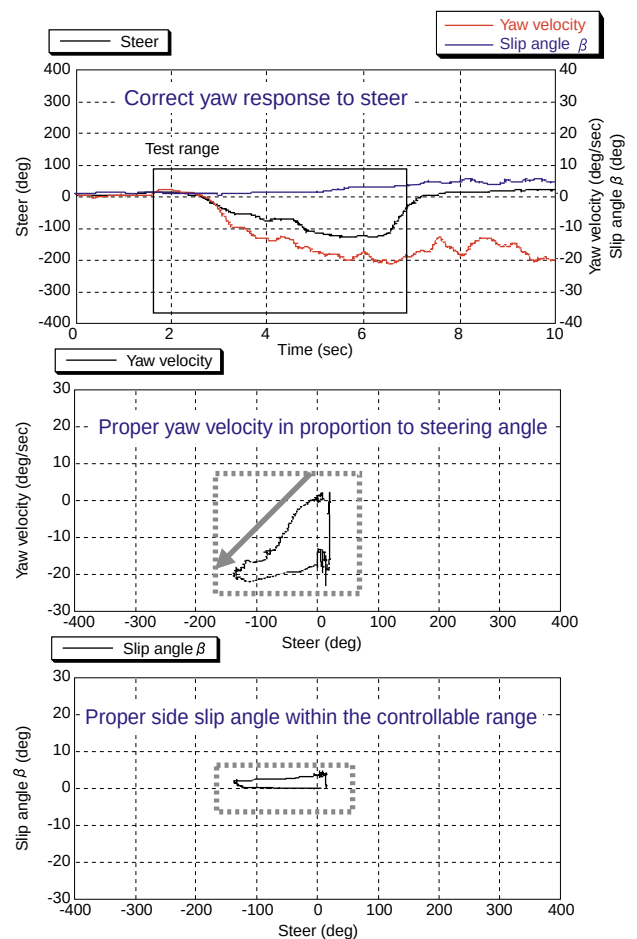


Fig. 8 50R J turn test on snow with VSA

4.2 50R Braking in Turn Test (sudden braking while turning)

The test mode and images of a vehicle driving on the test course are shown in Fig. 9.

Fig. 10 shows the tire grip limits are exceeded and the vehicle quickly diverges outward from the target line when VSA is not in operation. In contrast, as shown in Fig. 11, when VSA does operate, stopping distance is reduced 15%.

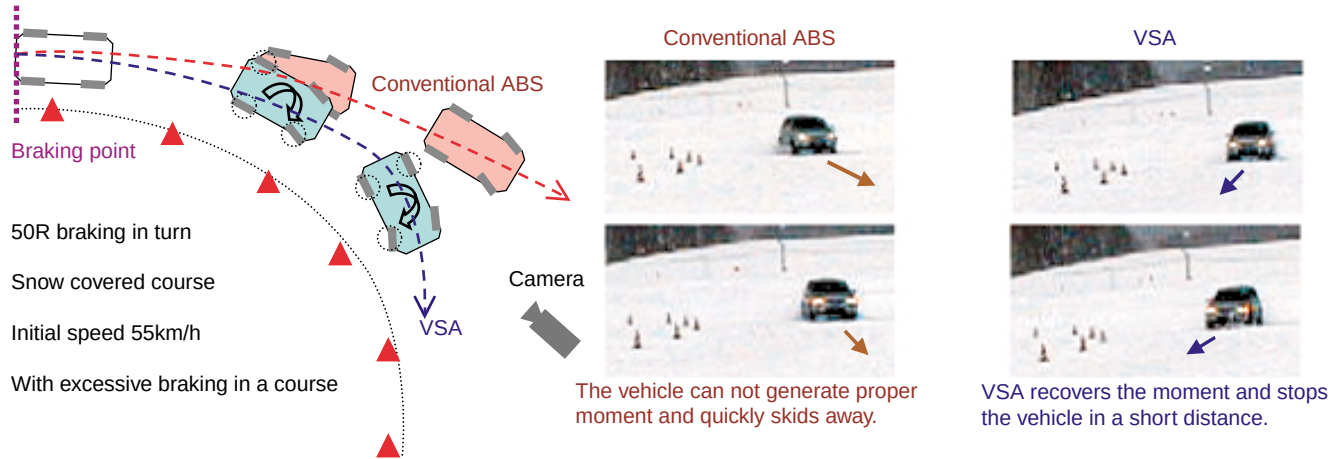


Fig. 9 50R braking in turn test

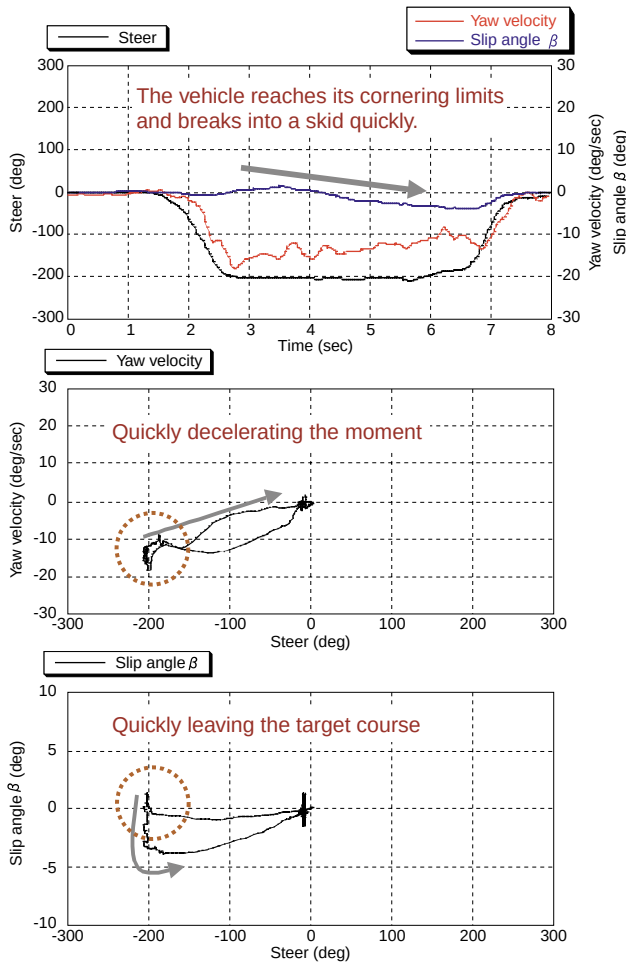


Fig. 10 50R brake in turn test on snow without VSA

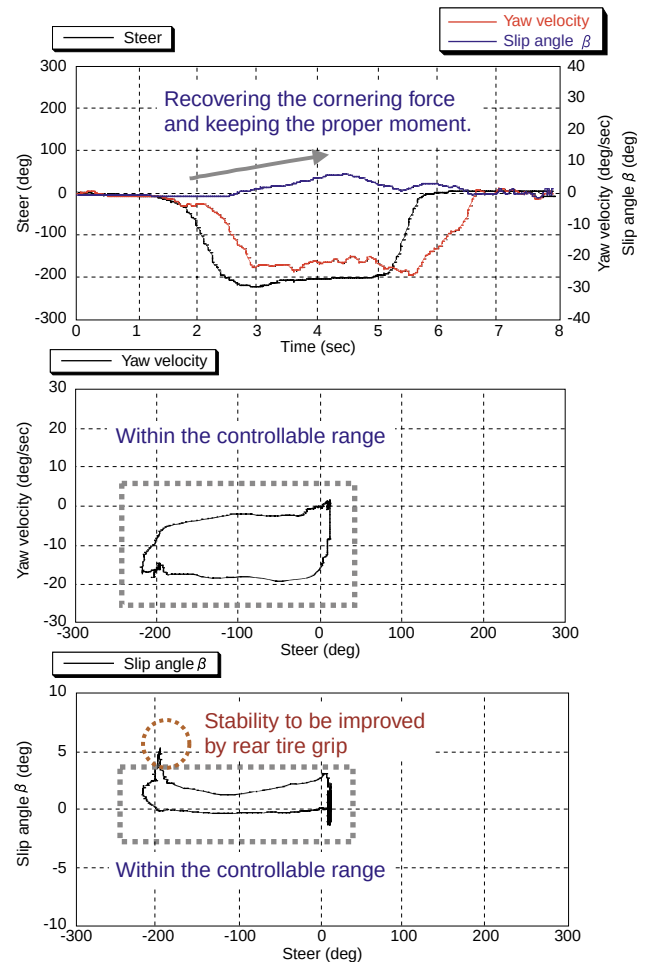


Fig. 11 50R brake in turn test on snow with VSA

4.3 Double Lane Change (collision avoidance steering)

The test mode and images of a vehicle driving on the test course are shown in Fig. 12.

Fig. 13 shows that there is a sudden increase in yaw moment when the vehicle returns to its original lane after an avoidance maneuver. It will enter into an over-steer

condition if VSA does not operate. In contrast, as shown in Fig. 14, when VSA does operate, yaw moment and side slip angle restricting controls are quickly applied, so that stability is generally maintained and a more effective steering state is achieved to help prevent over-steer. This is realized with the control system predicting the excessive moment that will occur at the next turn based on the yaw movement in the initial avoidance steering.

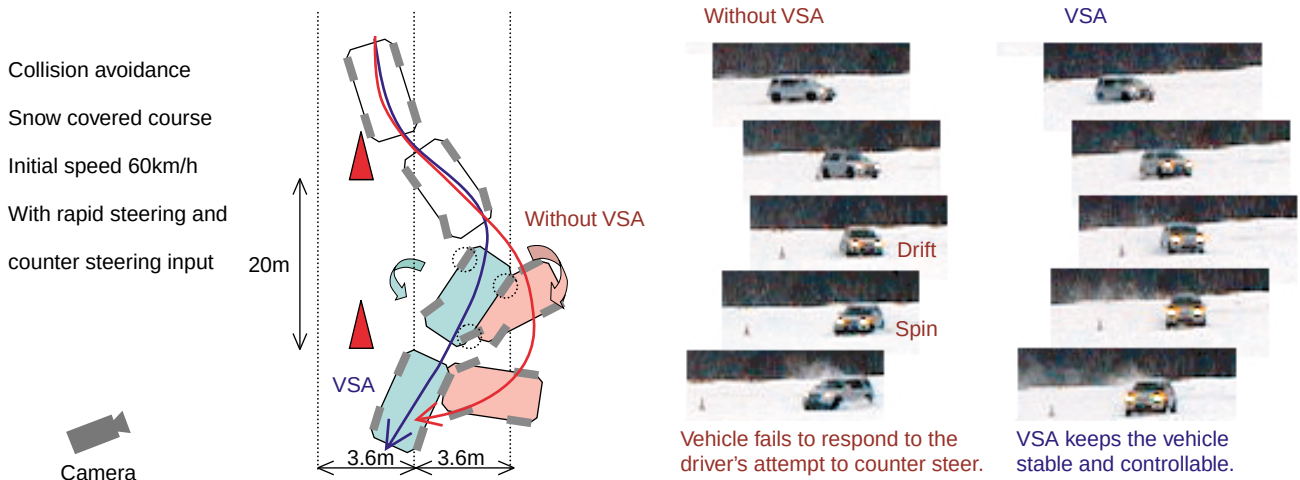


Fig. 12 Collision avoidance test

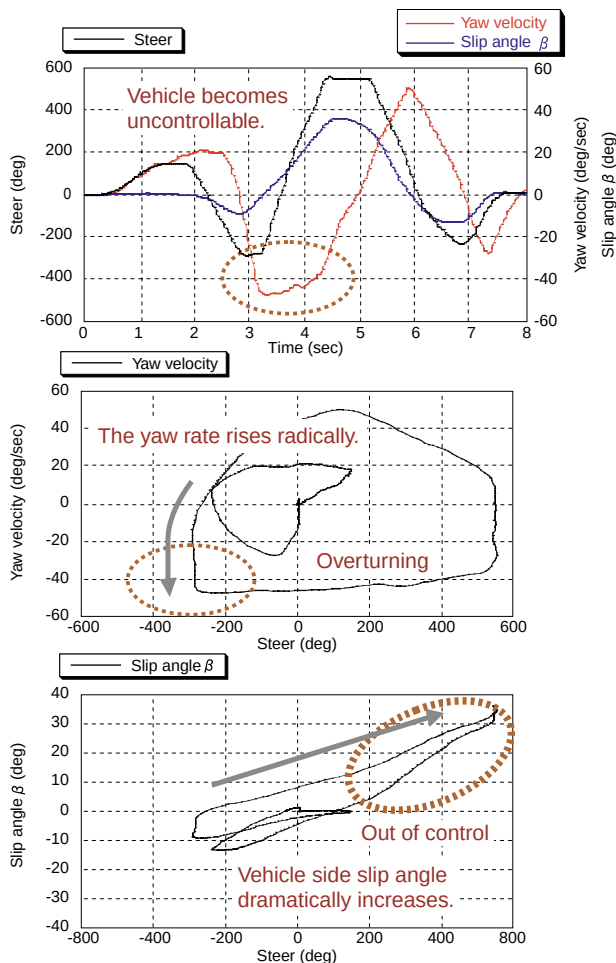


Fig. 13 Collision avoidance test on snow without VSA

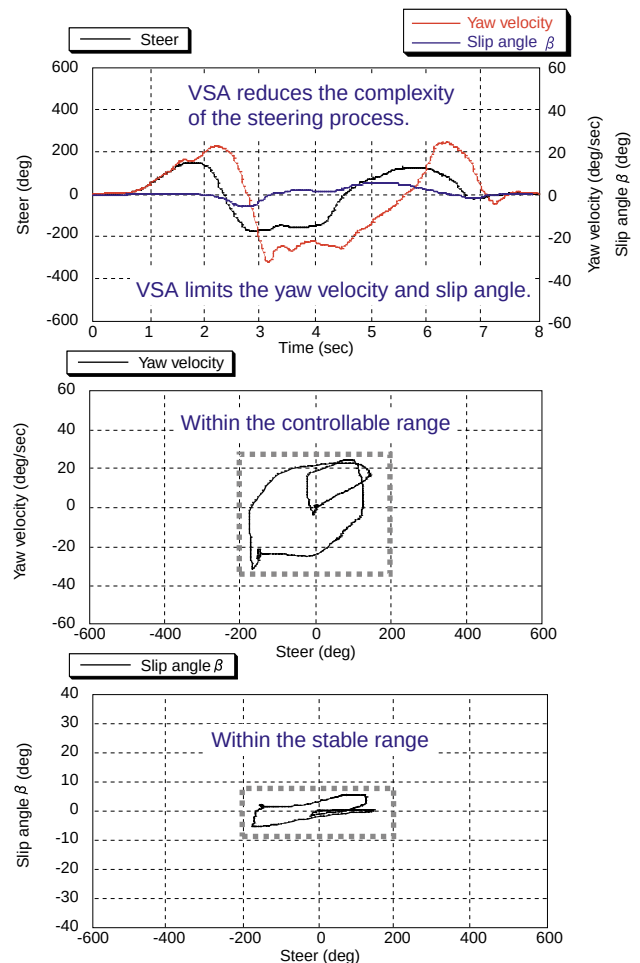


Fig. 14 Collision avoidance test on snow with VSA

4.4 Continuous Slalom (driving on winding roads)

Fig. 15 shows the test mode and photographic images of the actual vehicle while driving on the course.

As shown in Fig. 16, without VSA vehicle, behavior becomes increasingly unstable with each turn, so there is an increase in both steering and correction. In contrast, as

shown in Fig. 17, both side slip angle and yaw moment are controlled more appropriately and quickly with VSA control. Thus, steering is more stable. This has the benefit of reducing driver stress and fatigue, and of helping reduce the frequency of operating errors.

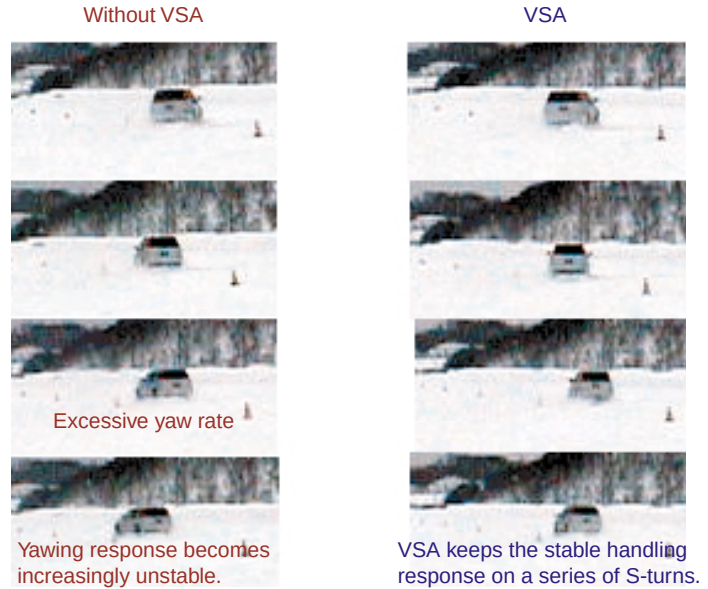
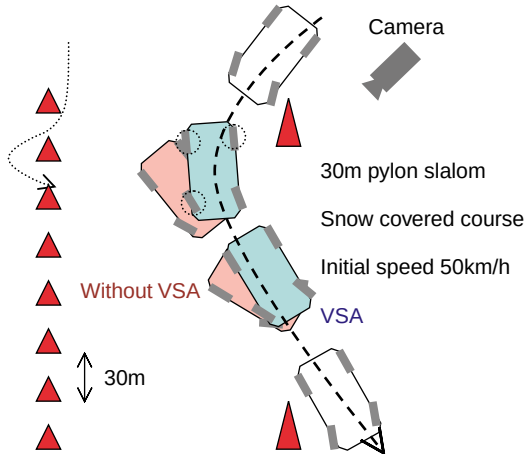


Fig. 15 Slalom test

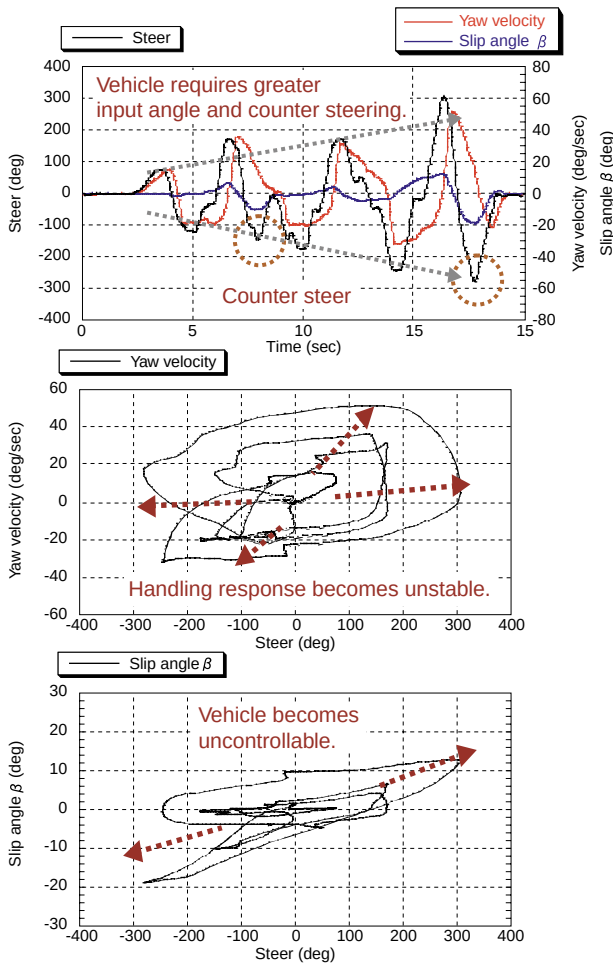


Fig. 16 Slalom test on snow without VSA

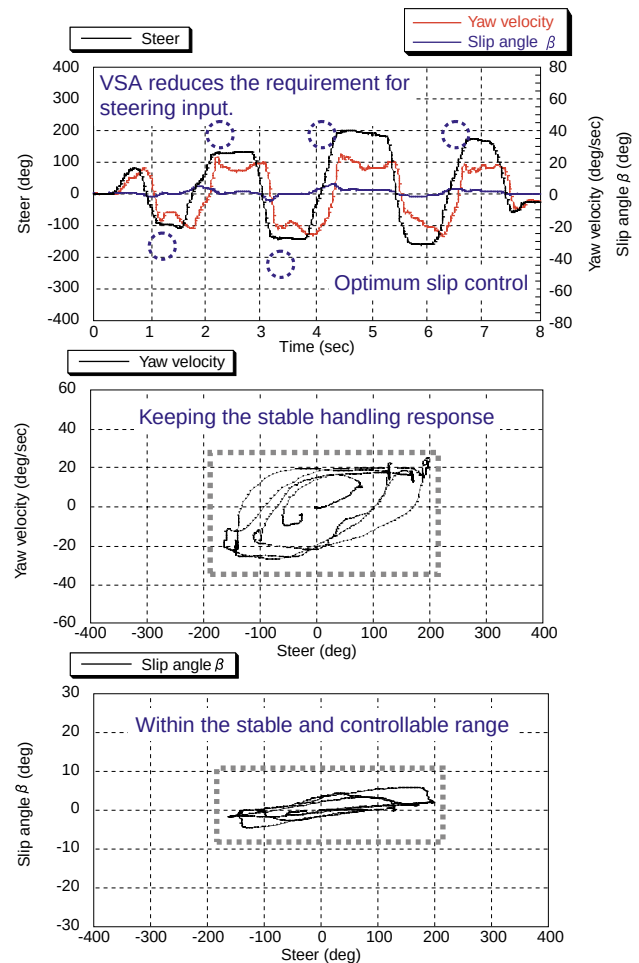


Fig. 17 Slalom test on snow with VSA

5. Observations

This paper will next discuss the effects of VSA on enhancing stability and steerability on ice- and snow-covered roads based on the results of the four tests outlined above.

(1) J-turn

Owing to the effects of deceleration control on the two rear wheels and under-steer control of the front inside wheel, it is possible to turn the vehicle while generally maintaining stability. In particular, yaw moment rises in proportion to the steering angle, thereby enhancing handling characteristics. However, it is necessary to further restrict drift-out from the point of view of potential collision avoidance.

(2) Braking in Turn

Stability has also been enhanced with a 15% reduction in stopping distance during turning while braking. However, the issue of divergence from the target line (caused by initial under-steer) remains, and further enhancement is necessary. In order to achieve this enhancement, it is necessary to develop predictive technology that, for example, anticipates not only the vehicle movement state in real-time but also the road situation ahead (for example, turning radius, etc.), to then apply advance speed control.

(3) Collision Avoidance Operation

Avoidance performance is enhanced even in situations where the vehicle sways widely due to rapid left and right steering, such as when avoiding an obstacle in the road. This performance is achieved through the stabilization of vehicle behavior resulting from the prediction of sudden increases in yaw rate and the early application of control.

(4) Slalom

The results of generally maintaining optimum steering characteristics during a continuous slalom are an enhancement in vehicle behavior stability and, consequently, allow for a reduction in fatigue.

6. Conclusions

The use of VSA control is beneficial in reducing driver fatigue when driving on ice- or snow-covered roads, and in reducing the likelihood of collisions.

- (1) Over-steer caused by collision avoidance, a series of S-turns, winding roads, etc. can be effectively reduced with the control that predicts the related difficulties in advance and improves rear tire grip.
- (2) Drift-out and under-steer caused by turning at excessive speeds or that occur during sudden braking can be effectively reduced, in comparison with conventional vehicles, due to a decrease in stopping distance and enhancements in handling characteristics. However, on ice- or snow-covered roads, where slightly excessive speeds or an operating error could lead to an accident, further enhancements are required in order to minimize divergence from the traffic lane.

7. Towards the Development of Active Safety Technology

Development has been proceeding with the goal of vehicle movement control that is highly effective in accident prevention. However, in order to make further improvements to safety, it will be necessary to develop the technology required to achieve a higher level of active safety, including technology that incorporates information surrounding the vehicle and new sensing technology.

Also, it is said that the leading cause of many collisions is driver error. Therefore, it is necessary to carry out investigative researches in external factors (vehicle behavior, road environment) and internal factors (drivers' state of mind) that compound to create conditions leading to operating errors as well as the estimation of vehicle behavior and road surface friction coefficients. In the future, in addition to analysis of vehicle dynamics and road conditions, analysis of human factor dynamics must be pursued in the development of accident prevention technology.

References

- (1) Kin, K., Yano, O., and Urabe, H., Enhancements in Vehicle Stability and Steerability with Slip Control, Honda R&D Technical Review Vol. 13, No. 1, p. 91 – 98 (2001)

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