

Development of Agile Handling Assist

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ABSTRACT

Agile Handling Assist has been developed in order to increase vehicle responsiveness and stability, offering users handling that is both exhilarating and secure. To realize the new system, a unique Honda Agile Handling Assist logic was incorporated in high-function Vehicle Stability Assist. By contrast with Vehicle Stability Assist, which goes into operation in the limit range, Agile Handling Assist operates from the daily use range, applying light braking force, unnoticeable to the driver, to the inner wheels when the steering wheel is turned, and to the outer wheels when the steering wheel is returned, in order to increase responsiveness and stability. The system has been put into mass production in the 2014 model year ACURA RLX.

1. Introduction

The automobile is the very symbol of personal mobility, and a level of handling performance that offers the driver the joy of vehicle operation is therefore demanded. Today, the results of performance evaluation tests by actors including public agencies and motoring magazines are available to consumers, and are being used as standards of judgment when purchasing an automobile. Honda has developed and mass produced numerous handling technologies to realize comfortable and immediate responsiveness to the driver's steering operations. The Active Torque Transfer System (ATTS)⁽¹⁾ increased ease of handling by controlling the allocation of drive force to the left and right wheels of FF vehicles, and was employed in the 1997 model Prelude. Following on from this, the company developed Super Handling-All Wheel Drive (SH-AWD)⁽²⁾, a system that controls drive force to all four wheels of AWD vehicles, and employed it first in the 2005 model LEGEND. More recently, the company has developed Precision-All Wheel Steer (P-AWS), a system that controls the rear toe angle, and which has been applied in the 2013 model ACURA RLX. Honda has also expanded the range of operation of its Vehicle Stability Assist (VSA), a safety function that formerly went into operation at the turning limit in order to control vehicle instability, to the entire daily use range, and has worked to boost handling performance by means of brake control. Here, however, the issues have been the development of new control logics and achieving the quietness and durability of standard VSA. A high-function VSA has now been developed that, in addition to danger avoidance functions, also offers functions that increase user convenience, for example a hill-hold function and a low-speed following function, and

also boasts increased quietness and durability. Using this high-function VSA, a control logic based on a new concept has been developed for Agile Handling Assist (AHA), a handling function that applies brake control across the daily use range and increases automotive responsiveness and stability performance.

2. Purpose of AHA and Development Goals

The purpose of AHA is to increase responsiveness and stability performance in relation to steering operations by the driver.

AHA reduces corrective steering, and offers the driver agile, exhilarating, and secure handling performance.

Concretely, the following three aims were set for the development of AHA:

- (1) Increased steering responsiveness
- (2) Market appeal, as exemplified by a smooth control feel
- (3) Increased at-the-limit handling performance

3. Operating Scenarios and Effects of AHA

The operating scenarios for AHA will be explained with reference to Fig. 1. The horizontal axis shows the degree of turning of the vehicle, and zero represents the commencement of straight-line driving: the further to the right, the closer to the turning limit. The vertical axis shows the degree of operation of the steering wheel, with zero representing fixed steering: the further upward, the more rapid the steering operation.

In the upper left area of the AHA operating range, shown as (1), control is applied to agilely turn the vehicle and achieve an early convergence of roll when a sudden steering operation is engaged from a state close to straight-

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line progression, for example a lane change to avoid an obstacle or passing through a roundabout.

In the lower right area of the AHA operating range, shown as (2), steering operation is applied when turning, with the vehicle going from the medium to the high range of lateral acceleration. This encompasses such scenarios as steering around S-shaped curves on a winding road or turning the steering wheel while cornering. Here as well, AHA offers agile turning, making it easy for the driver to trace the desired line.

In the upper right area of the AHA operating range, shown as (3), rapid steering operation is applied when turning, with the vehicle going from the medium range of lateral acceleration to the high range of lateral acceleration. This includes such scenarios as a rapid maneuver to avoid an obstacle or a rapid avoidance maneuver during a turn. By realizing smooth and agile handling close to the limit, AHA offers the driver a sense of security that is unaffected by conditions on the road.

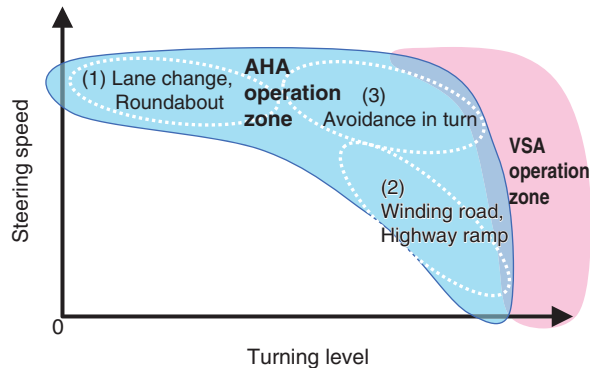


Fig. 1 AHA activation scenario

4. System Composition

The AHA functions were realized by adding an original control logic to high-function VSA, which offers the merits of high levels of responsiveness, quietness and durability.

4.1. Hardware

High-function VSA realizes increased market appeal, responsiveness to brake pressure, and durability compared to standard VSA.

In concrete terms, the number of cylinders in the pump has been increased, (high-function VSA uses six pistons against the two used in standard VSA), reducing pumping pulsation, and thus reducing operating noise and vibration. At the same time, the discharge volume has been increased, increasing responsiveness to brake pressure. In addition, a high-capacity motor has been employed, resulting in greater durability. Motor vibration and operating noise have been reduced by increasing the control frequency of motor control. This increase in control frequency also increased heat generation, leading to the use of a heat-dissipating configuration in which the sides of the Electronic Control Unit (ECU) case are manufactured from aluminum, and the motor control elements are connected using a heat-conductive adhesive.

4.2. Software

A unique AHA control logic was developed and incorporated in the high-function VSA ECU software.

4.2.1. AHA control logic

The composition of the AHA control logic will be discussed with reference to Fig. 2.

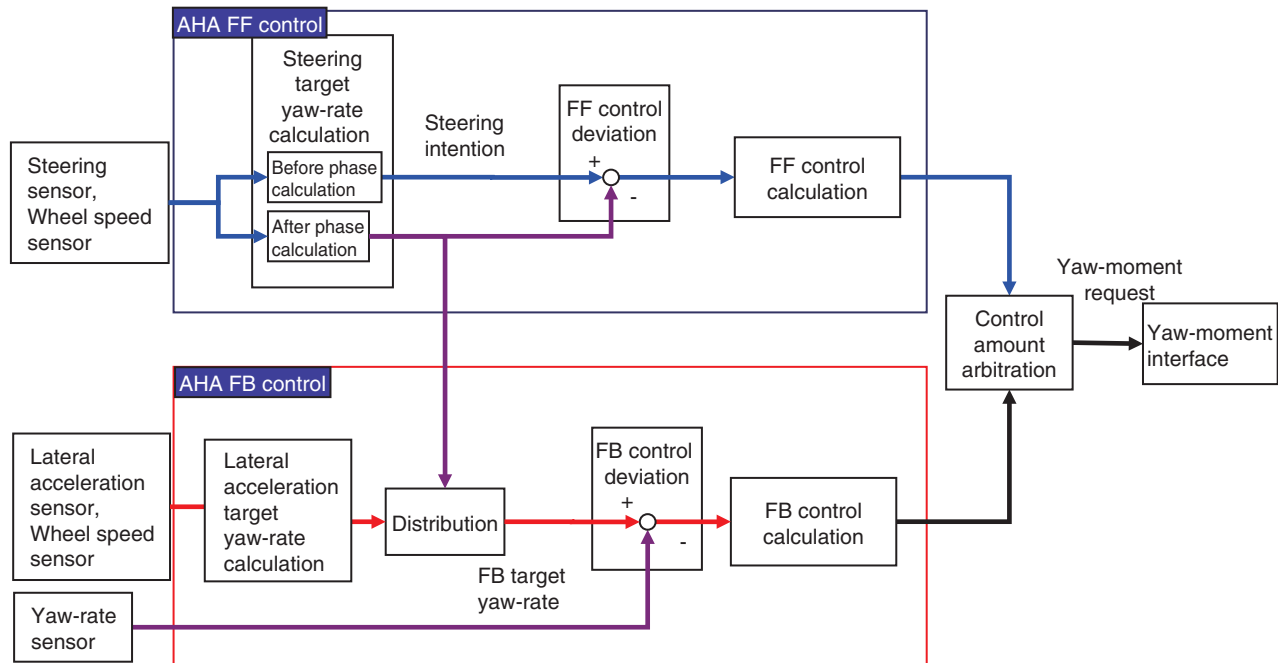


Fig. 2 AHA control logic

The control logic is made up of feed-forward (FF) control and feedback (FB) control.

- (1) FF control applies a light braking force to the inner wheels when the steering wheel is turned, and to the outer wheels when the steering wheel is returned, in order to reduce phase lag (Fig. 3). Using as a parameter the difference between a steering target yaw rate at which there is no phase lag, as determined from the steering angle, and a steering target yaw rate that considers phase lag, the control judges when to initiate and conclude control by comparing this parameter with the threshold value for FF control. In addition, the control calculates the feed-forward yaw-moment demand. In terms of operating scenarios, FF control is effective when rapid steering operation is initiated from a state of straight-line progression (Area (1) in Fig. 1 in Chapter 3) and when the steering wheel is operated while the vehicle is turning in the medium to high range of lateral acceleration (Area (2) in Fig. 1 in Chapter 3).
- (2) FB control is applied to make the actual yaw rate conform to the target yaw rate. However, the target yaw rate can be modified in line with the driver's operation of the steering wheel, and the driver's intended steering operation is thus reflected. This control realizes smooth and agile vehicle motion at close to the turning limit. Like VSA, the logic calculates a steering target yaw rate that considers phase lag and reflects the driver's intention, and a target yaw rate for lateral acceleration that estimates the turning limit. When the driver turns the wheel in excess of the turning limit or the target yaw rate is greater than the target yaw rate for lateral acceleration, VSA calculates the final target yaw rate, to realize stable control of the vehicle, as approaching the target yaw rate for lateral acceleration. By contrast,

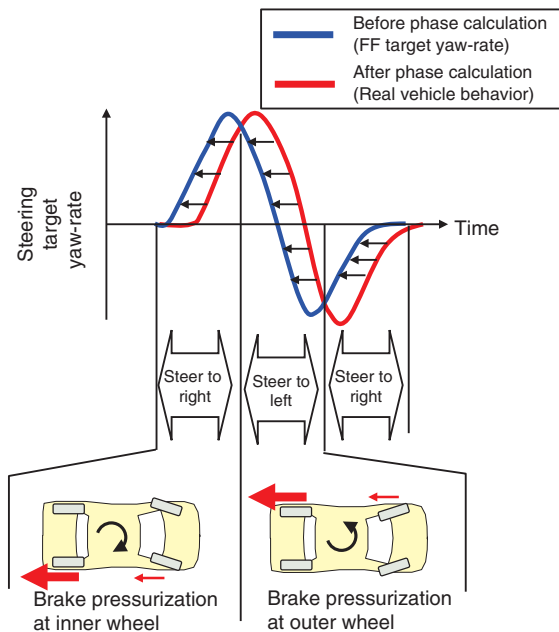


Fig. 3 AHA FF control

AHA FB control calculates the FB target yaw rate as approaching the steering target yaw rate, thus offering a form of control that reflects the driver's intention to turn the steering wheel. If the vehicle then becomes unstable when the driver returns the wheel or due to a sudden change in the actual yaw rate, the control calculates the target FB yaw rate as approaching the lateral acceleration target yaw rate, realizing control that both reflects the driver's intention and helps to ensure stability (Fig. 4). Using the difference between the target FB yaw rate and the actual yaw rate as a parameter, FB control judges when to commence and when to conclude operation based on comparison of the parameter with the threshold value for FB control. In addition, the logic calculates the FB yaw-moment request. FB control is effective in situations in which rapid steering operations are initiated while turning in the medium to high ranges of lateral acceleration (Area (3) in Fig. 1 in Chapter 3).

- (3) The necessary yaw moment for FF control and the necessary yaw moment for FB control are added, and the resulting figure is the necessary yaw moment for AHA control.
- (4) Figure 5 shows the composition of the ECU software for high-function VSA.

If the AHA control logic used an external ECU, and sent commands to VSA via CAN communications, delays in CAN communication would result in delays in response. For this reason, the AHA control logic was incorporated in the ECU software of high-function VSA.

Based on calculation results, the necessary yaw moment for AHA control is output to a yaw moment interface between AHA and VSA. The yaw moment interface reconciles the necessary yaw moments for AHA and VSA control, producing a final yaw moment for control. This is then converted into brake pressure, and brake pressure control is applied. The yaw moment interface is also provided with a limiter that controls the upper limit of the yaw moment necessary for AHA control, helping to maintain safety if the sensors malfunction.

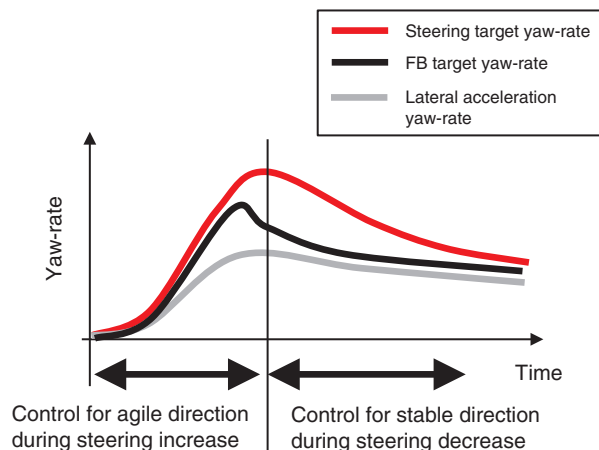


Fig. 4 AHA FB control

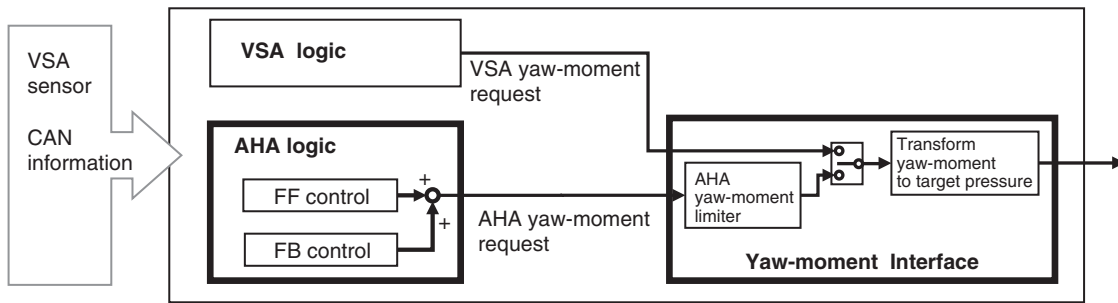


Fig. 5 VSA software structure

5. Effect in Boosting Performance

5.1. Increased Steering Responsiveness

In order to verify the effect of AHA in increasing steering responsiveness, the response time of yaw rate to steering wheel input was measured during a J-turn. Commencing at an initial vehicle speed of 60 km/h, the steering wheel was turned at a speed such that it would reach 90 deg in 0.5 s, and held at an angle of 90 deg. Response time was defined as the time from the steering angle reaching 45 deg to the time at which the yaw rate produced reached 90% of its maximum value. The results are shown in Fig. 6. The use of AHA reduces response time by 55 ms, from 330 ms to 275 ms. This demonstrates that the system realizes the development aim of achieving increased steering responsiveness.

5.2. Market Appeal

In order to verify the smooth control feel offered by AHA, steering angle and yaw rate were measured

during slalom driving on a dry road surface. The Lissajou waveform for yaw rate against steering angle is shown in Fig. 7. From an initial vehicle speed of 60 km/h, a sine wave input was applied at a cycle of 0.5 Hz, with a maximum steering angle of 90 deg. As the Lissajou waveform shows, when AHA was not in operation, the rate of increase or decrease in yaw rate against the steering angle changes, there is no linearity, and hysteresis also tends to be high.

By contrast, when AHA is in operation, the rate of increase or decrease in yaw rate is constant, linearity increases, and hysteresis is reduced. Realizing control linearity represented an issue in the application of brake pressure control from the daily use range, and this result indicates that the issue has been addressed and that the system contributes to increased linearity.

The results also indicate that the system has the merit of increasing hysteresis. These results demonstrate that the system realizes the development aim of achieving a smooth control feel.

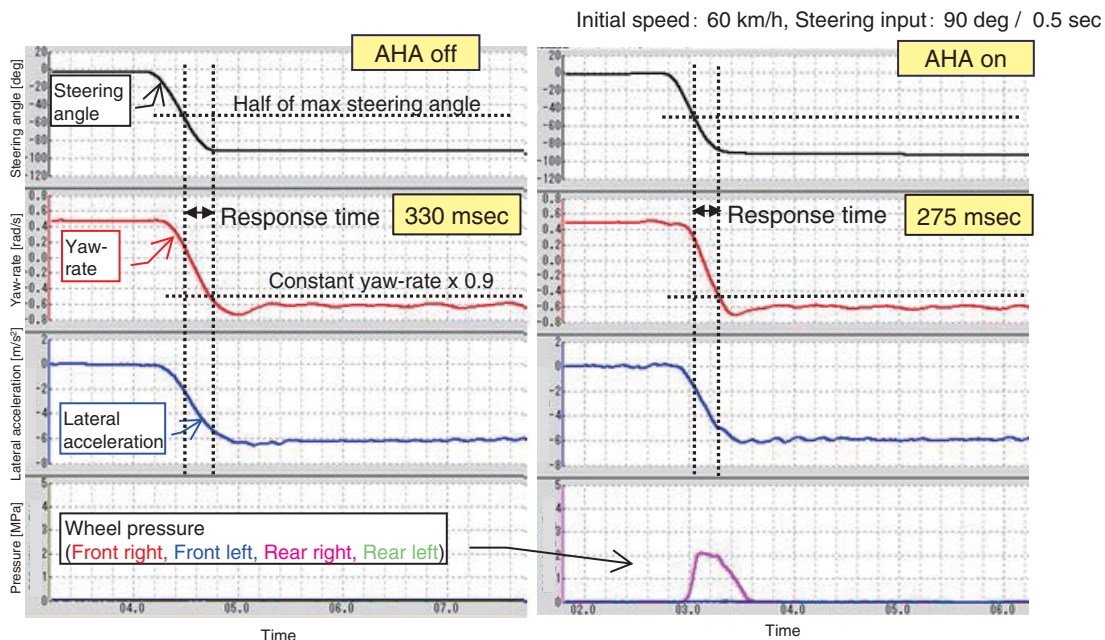


Fig. 6 J turn test result

5.3. Increased At-The-Limit Handling Performance

Test modes used by motoring magazines and public agencies were used on a Honda test course in order to test this performance factor.

5.3.1. Low-speed slalom driving on dry road

This is a test mode used by European motoring magazines. Twenty pylons are set up at intervals of 18 m, and the test vehicle passes between them at the highest speed possible, commencing from an initial vehicle speed of 50 km/h. Tests using this mode were conducted on a Honda test course with the results shown in Fig. 8. When

AHA was functioning, the time for the vehicle to pass between the pylons was reduced by 1.3 s. In addition, the Lissajou waveform of the yaw rate against steering angle demonstrates a reduction in yaw rate hysteresis, indicating an increase in yaw rate tracking performance and a reduction in the amount of necessary steering operation. This shows that the increase in responsiveness and ability to trace steering operation in the low-speed range and close to the limit offered chiefly by AHA FF control helps to eliminate excess steering operation, making it possible for the vehicle to pass more quickly between the pylons.

Slalom initial speed: 60 km/h,
Steering input: 90 deg, 0.5 Hz

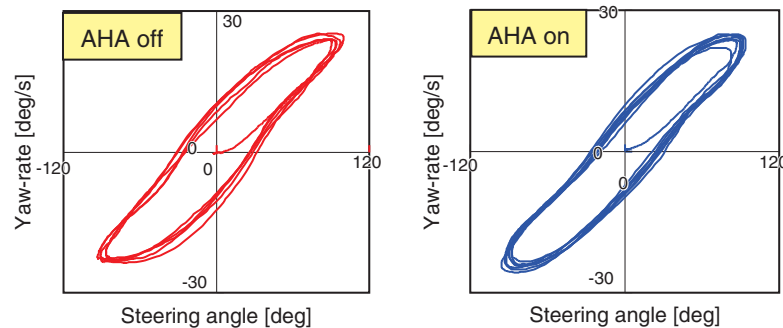
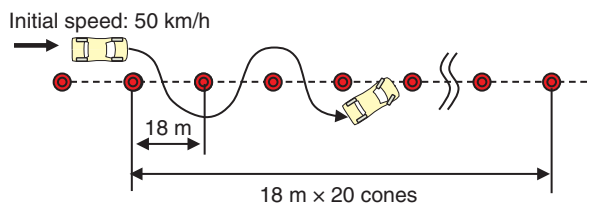


Fig. 7 Linearity control test result

Test mode of dry slalom at low speed



Fastest time

AHA off	24.6 sec
AHA on	23.3 sec

Maximum steering angle

AHA off	172.6 deg
AHA on	154.9 deg

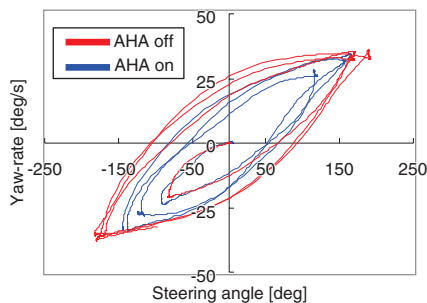


Fig. 8 Dry slalom test result at low speed

5.3.2. High-speed slalom driving on dry road

This is a test mode used by U.S. motoring magazines. Seven pylons are set up at intervals of 100 ft, and the test vehicle passes between them at the highest speed possible. Tests using this mode were conducted on a Honda test course. The results are shown in Fig. 9. When AHA was functioning, the time taken to pass between the pylons was reduced by 0.29 s. In addition, control of yaw rate diffusion made it possible to continue slalom driving with stable steering operation, and a reduction in the amount of steering operation was also observed. This indicates that the increased responsiveness, ability to track steering operation, and stability in the high-speed range and close to the limit offered by AHA FF and FB control offers the same high level of handling performance as was the case at low speed.

5.3.3. Slalom driving on low- μ road

This is a Honda test mode. Six pylons are set up at intervals of 30 m on a low- μ basalt road, and the test vehicle drives between them at the highest speed possible. These tests were conducted on a Honda test course with the results

shown in Fig. 10. When AHA was in operation, the time to complete the course was reduced by 1.1 s. In addition, control of yaw rate diffusion made it possible to continue slalom driving with stable steering operation, and there was also a reduction in the amount of steering operation. This demonstrates that a high level of handling performance even at close to the limit on a slippery road surface is realized chiefly by AHA FB control.

5.3.4. V lane change on dry road

This is a test mode used by U.S. government agencies. During the test, the vehicle passes into the specified lanes at maximum initial speed. The results of tests conducted using this mode on a Honda test course are shown in Fig. 11. When AHA was in operation, maximum vehicle speed increased by 3.9 km/h. In addition, the control of yaw rate diffusion has reduced the amount of steering operation. This indicates that the increased agility, ability to track steering operation and stability close to the limit offered chiefly by AHA FB control increases danger avoidance performance.

Test mode of dry slalom at high speed

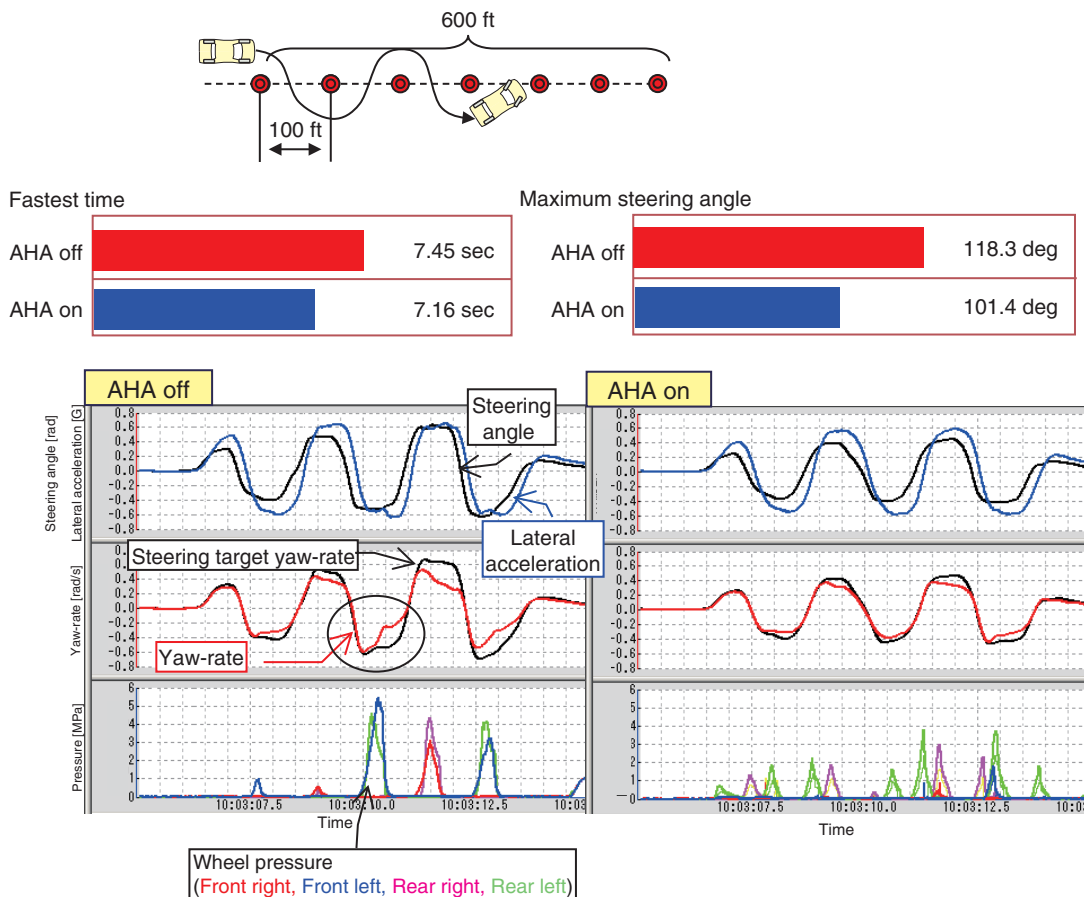
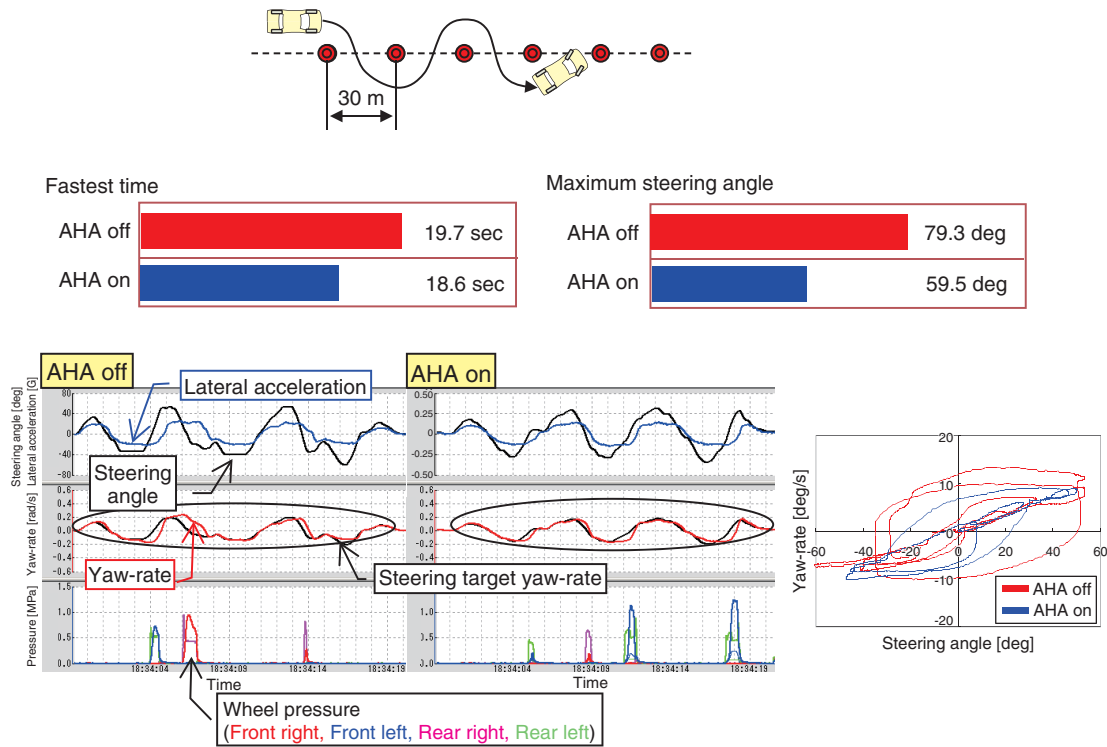


Fig. 9 Dry slalom test result at high speed

Test mode of low μ slalom

 Fig. 10 Low μ slalom test result

Test mode of dry V-lane change

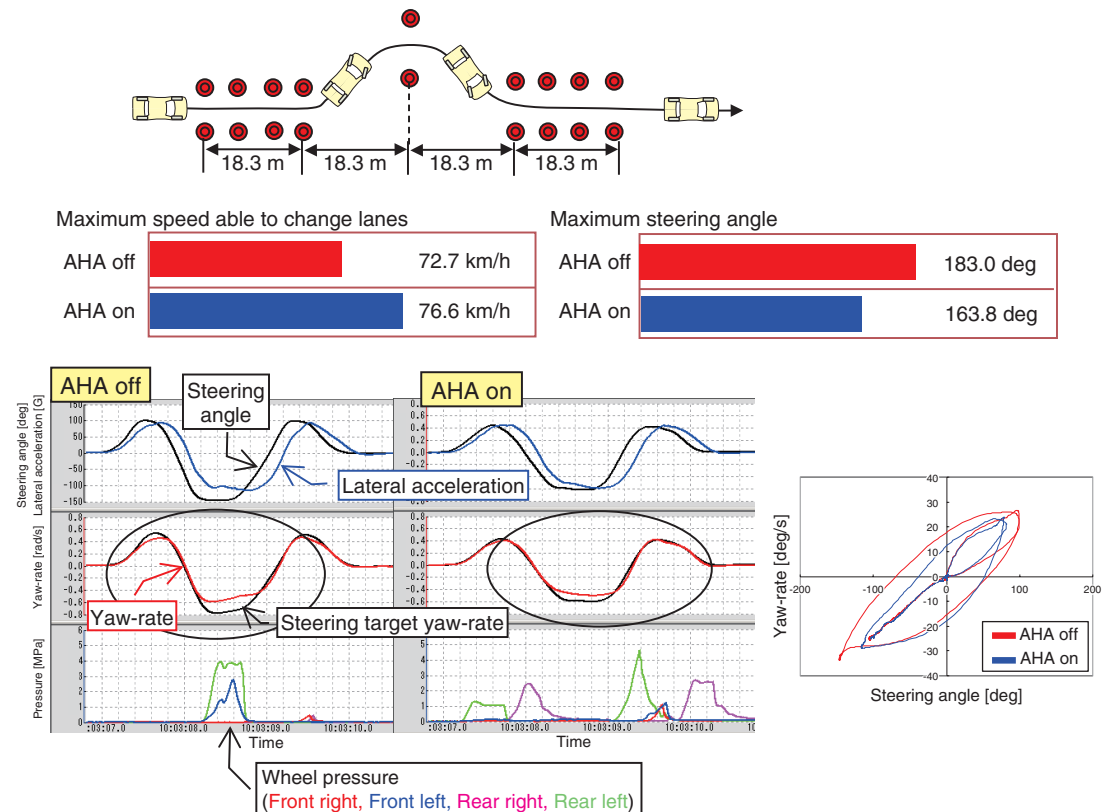


Fig. 11 Dry V-lane change test result

6. Effect of AHA in Combination with P-AWS

AHA and P-AWS have been used in combination in the 2014 model ACURA RLX. In order to help ensure stability at high speed, P-AWS applies control to make the phase of the steering angle of the rear wheels the same as the phase of the steering angle of the front wheels. At low speed, it applies control to make the phase of the steering angle of the rear wheels opposite to the phase of the steering angle of the front wheels in order to increase turn-in ability and create an inward-facing posture. A synergistic effect on handling was observed from the combination of AHA and P-AWS.

6.1. Responsiveness of Lateral Acceleration during Initial Stage of Steering when Inputting Rapid Steering Operation

A test mode in which lanes are changed while turning was used to study the effect of the system in this respect with the results shown in Fig. 12. When P-AWS was used in isolation, the application of rear-wheel reverse

phase control to generate a yaw rate resulted in good turn-in ability. The use of AHA in combination with P-AWS increased the lag in the response of lateral acceleration during high-frequency steering input, and the synergistic effect made it possible to realize ideal turning performance.

6.2. Increased Convergence of Yaw Rate in Relation to Steering Input under Low- μ and Other Limit Range Conditions

The effect of the system was studied using a test mode involving a single lane change on a low- μ road with the results shown in Fig. 13. When P-AWS was used in isolation, the application of rear-wheel reverse phase control to generate a yaw rate resulted in good turn-in ability even on a low- μ road. When AHA was then used in combination with P-AWS, AHA FB control increased the yaw rate convergence in the limit range that is characteristic of rear-wheel reverse phase steering, and the synergistic effect made it possible to realize ideal turning performance.

Test mode of lane change in turning

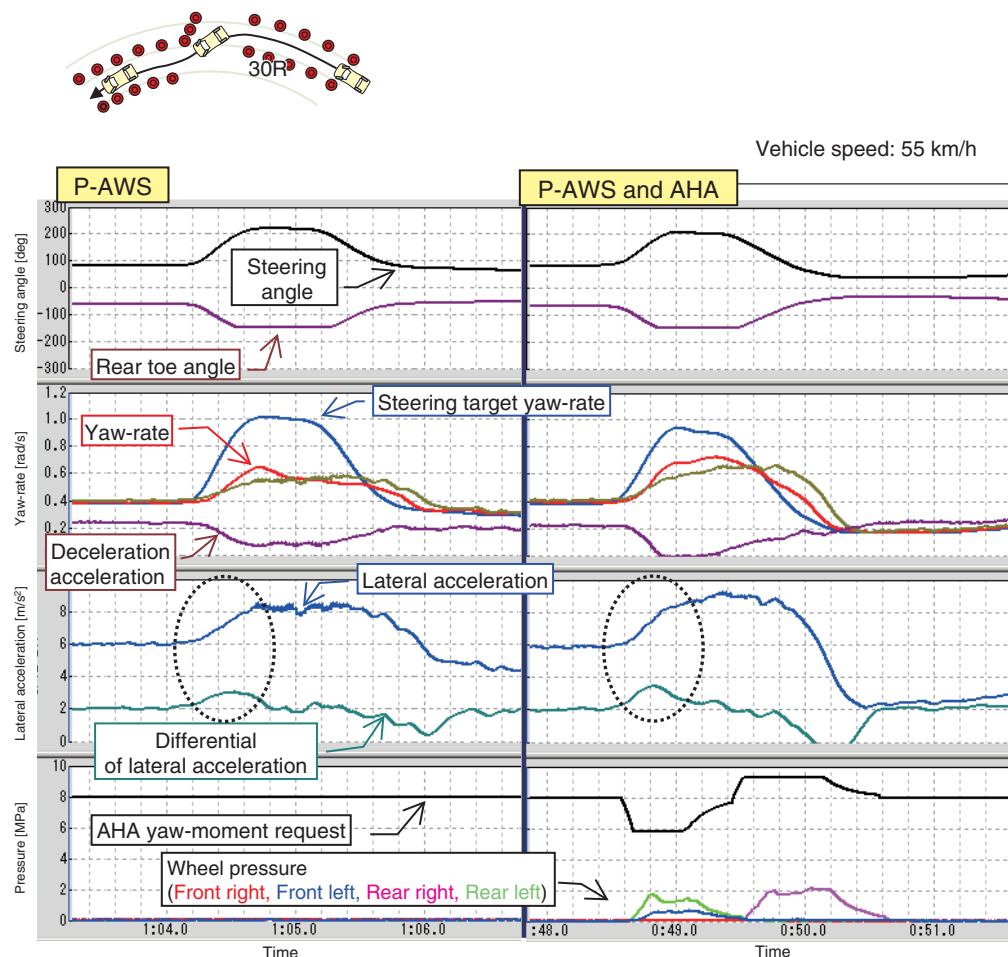


Fig. 12 AHA effect with P-AWS (part 1)

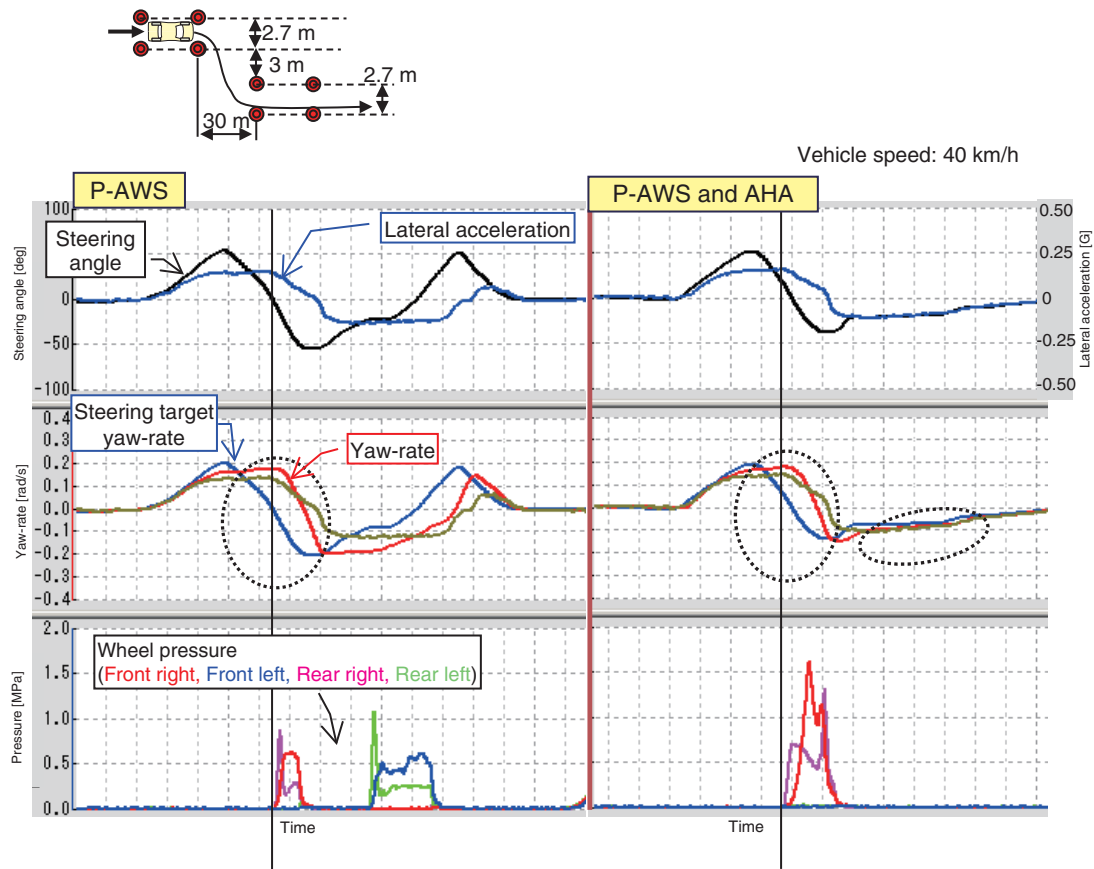
Test mode of low μ lane change

Fig. 13 AHA effect with P-AWS (part 2)

7. Conclusion

The following three aims for the development of AHA were realized, and the system is able to increase responsiveness and stability in relation to the driver's steering operation.

- (1) The system demonstrated an effect in increasing the responsiveness of yaw rate during a J-turn, indicating increased steering responsiveness.
- (2) During slalom driving, the steering-angle yaw-rate characteristic was linear and smooth, and the system thus displays sufficient market appeal.
- (3) Performance was increased in media test modes, indicating increased at-the-limit handling performance. AHA displayed a synergistic effect when used in combination with P-AWS, making it possible to realize ideal turning performance.

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