Technology Introduction

Development of Automotive Semi-Active Damper Control

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1 Introduction

The number of vehicles with semi-active dampers is still growing, and even some small vehicles use them, as seen in the example of Alfa Romeo MiTo, etc. In such a situation, the needs greatly differ for each manufacturer, vehicle rank, and vehicle type, as different manufacturers focus on different aspects, such as vehicle performance, cost, stable driving performance, comfort, etc.

We need control technologies that we can prepare in anticipation for these various needs. KYB's initiatives toward such needs include the development of semi-active damper control for magnetorheological fluid dampers, semi-active damper control for proportional solenoid dampers, etc. These control technologies provide both sprung mass control and unsprung mass control. In this control development, we have added more variations to these control technologies with the aim of responding to various needs. Specifically, this project developed control technologies that can further expand the adjustment range of vehicle performance by changing the number of sensors while providing both sprung mass control and unsprung mass control. This report introduces these technologies.

2 Sensors for Semi-active Damper

Firstly, I would like to explain the sensors for semi-active damper installed on vehicles. Our semi-active damper control requires 7 sensors for the semi-active damper control. The breakdown of these sensors includes 3 accelerator sensors that detect the vertical direction of sprung mass and 4 suspension stroke sensors, which are positioned as shown in Fig. 1. In this sensor configuration, sprung mass oscillation is detected through the accelerator sensors, and unsprung mass oscillation is detected through the stroke sensors. We have decided to remove the stroke sensors, which are more expensive than accelerator sensors and have more installation restrictions by changing the number of sensors from 7 sensors.

To develop semi-active damper control with a different number of sensors, we have changed the sensor installation positions according to the number of sensors. Reducing stroke sensors means that the unsprung mass oscillation information that had previously been obtained can no longer be obtained. Due to this, we must enable unsprung mass oscillation detection through sensor position changes.

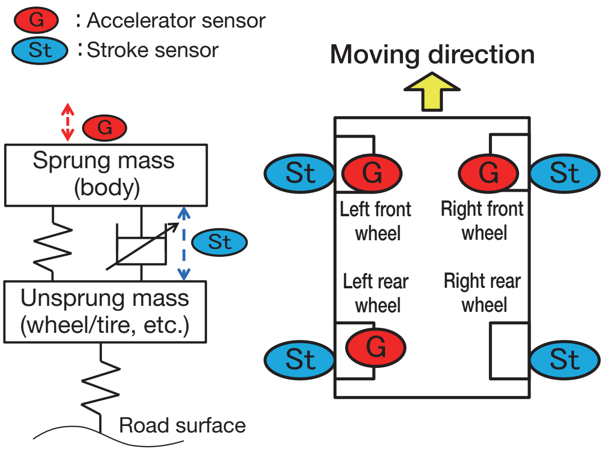

Fig. 1 Position diagram for 7 sensors

In this project, we developed the semi-active damper control with 5 sensors and the semi-active damper control with 3 sensors as semi-active damper control by reducing the number of sensors. Fig. 2 shows the arrangement plan for 5 sensors, and Fig. 3 shows the arrangement plan for 3 sensors.

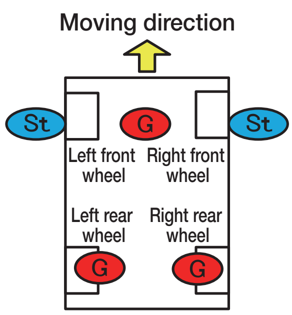

Fig. 2 Position diagram for 5 sensors

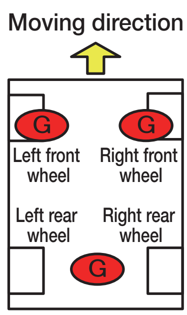

Fig. 3 Position diagram for 3 sensors

With 5 sensors, we removed the stroke sensors on the rear wheel side and placed an accelerator sensor over each rear wheel. The objective of this change was to thoroughly control the oscillation of the front wheels, which are the first wheels to capture the road surface input, so the information from the front wheels was prioritized. In other words, the unsprung mass oscillation for the front wheels is detected with stroke sensors to control the oscillation. On the other hand, unsprung mass oscillation on the rear wheels must be detected somehow in place of the removed stroke sensors. Therefore, the unsprung mass oscillation components, which are communicated to sprung mass, are extracted from the accelerator sensor placed over each rear wheel, enabling the detection of unsprung mass oscillation of the right rear wheel and left rear wheel. In addition, extraction of the unsprung mass oscillation components will be explained later.

With 3 sensors, we removed all of the stroke sensors. An accelerator sensor was placed over each front wheel in order to make the unsprung mass oscillation for the right front wheel and the left front wheel detectable. The reason that 2 sensors were placed on the front wheel side is because we focused on the front wheels, which are the first wheels to capture the road surface input, as with 5 sensors. In terms of the rear wheels, the unsprung mass oscillation obtained from the accelerator sensor between the rear wheels is distributed evenly to the right and left wheels.

3 Semi-active Damper Control in Response to the Number of Sensors

Next, I would like to explain the control for each number of used sensors (7, 5, and 3). In this development, we differentiated not only the control for each number of sensors but also two types of control, one focusing on comfort and the other on stable driving performance, by changing the control itself in addition to gain tuning. In other words, we developed control according to the number of sensors/vehicle performance, such as "comfort-oriented control with 3 sensors" and "stable driving performance-oriented control with 5 sensors" (Table 1). Table 1 shows the control of parts that especially contributed to the reduction of sensors and expansion of the performance adjustment range. In addition, I will omit the explanations regarding controls that are not affected by the number of sensors in this report. These controls include the steering control using steering wheel angles, vehicle velocity, horizontal acceleration, etc. and the control performed solely through gain tuning.

First, I would like to explain the control when the number of sensors is 7. When there are 7 sensors, not only the sprung mass oscillation but also the unsprung mass oscillation of each wheel can be detected. Due to this, even more detailed control can be implemented. We were especially able to increase the performance range for comfort-orientation as well as stable driving performance-orientation through the comfort control, the objective of which is to maintain the sprung mass flat during each unsprung mass oscillation cycle, and the road surface follow-up control, the objective of which is to follow the road surface rolling.

Table 1 Control in accordance with the number of sensors and vehicle performance

Number of sensors	Comfort-oriented control	Stable driving performance-oriented control
7	Comfort control Thrust absorption control Unsprung mass control	Road surface follow-up control Thrust absorption control
5	Differentiation of technologies for 7 sensors and 3 sensors	Differentiation of technologies for 7 sensors and 3 sensors
3	Thrust absorption control Unsprung mass control	Thrust absorption control

Fig. 4 shows the image diagram for sprung mass movements when comfort control is being performed. Comfort control uses skyhook control, which is used in common suspension control. This not only controls the extension/compression ratio of the damper's damping force against the sprung mass velocity in every unsprung mass oscillation cycle but also ensures that the damping force does not suddenly change when controlling the extension/compression ratio. This control improves comfort.

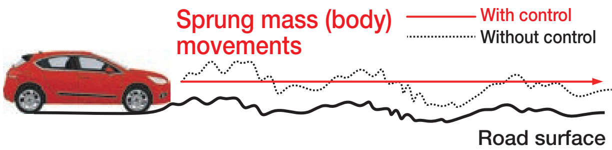

Fig. 4 Comfort control image diagram

Fig. 5 shows the image diagram for spring mass movements when road follow-up control is being performed. The road follow-up control controls the low-frequency damper velocity in every unsprung mass oscillation cycle. "Low-frequency damper velocity" here refers to the 1-2 Hz low frequency components that are extracted from the damper velocity, which is detected by the stroke sensors, through filtering. This enables the vehicle to follow vast rolling of road surfaces, improving the stable driving performance.

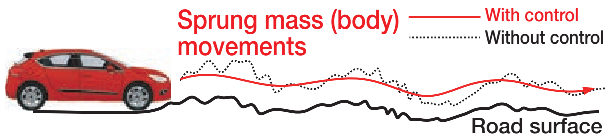

Fig. 5 Road surface follow-up control image diagram

Fig. 6 shows the image diagram for unsprung mass movements when unsprung mass control is being performed. Unsprung mass control increases the damping force according to the unsprung mass oscillation level. This enables the damping force to be reduced on road surfaces with minor unevenness, contributing to the improvement of comfort.

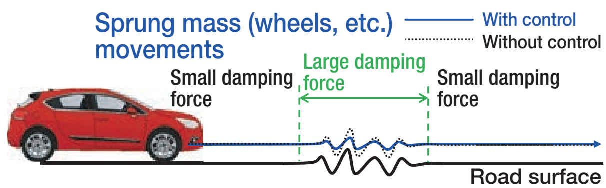

Fig. 6 Unsprung mass control image diagram

With 5 sensors, the sensor placement for the front wheels for oscillation detection is the same as that of 7 sensors. The sensor placement for the rear wheels is the same as that for the front wheels when the number of sensors is 3. Therefore, the control with 7 sensors and control with 3 sensors are used differently for the front wheels and the rear wheels. Due to this, I will omit the explanation.

When there are 3 sensors, we cannot obtain the information from stroke sensors, which we can obtain from 7 sensors. Due to this, we calculated alternative values by using accelerator sensors that detect the sprung mass oscillation to implement unsprung mass control. The unsprung mass oscillation components in addition to sprung mass oscillation information are superimposed on the accelerator sensors for sprung mass. Due to this, we have extracted only the unsprung mass oscillation components from the accelerator sensor values to only detect how much oscillation the unsprung mass had (unsprung mass oscillation level) (Fig. 7). As Fig. 7 shows, the oscillation level, which is calculated from the damper velocity that has been differentiated with the values detected by the stroke sensors, and the oscillation level, which is calculated from the sprung mass acceleration detected by accelerator sensors, draw almost the same waveforms. Due to this, we can say that the unsprung mass oscillation level can also be detected from sprung mass acceleration. Then, we implemented the control to increase the damper's damping force according to the detected unsprung mass oscillation level (unsprung mass control).

However, the detection accuracy is less than the detection of unsprung mass oscillation from stroke sensors. Due to this, we did not implement control for every unsprung mass oscillation cycle, which we did for 7 sensors. In addition, since the minimum damping force is enhanced for stable driving performance-oriented control, we did not implement the unsprung mass control.

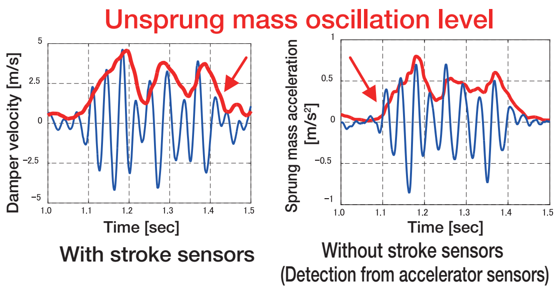

Fig. 7 Unsprung mass oscillation detection

The thrust absorption control, which is implemented in both control specifications, controls the distortion of the damping force waveform caused by valve cracking within the damper. The test result of this thrust absorption control for the damper alone is shown in Fig. 8.

This shows that the distortion of the damping force waveform within the green frame is reduced through the thrust absorption control. Although the distortion reduction seems small on the waveform, the reduction of this distortion absorbs the thrust feel during actual vehicle evaluation, improving the comfort.

Next, Fig. 9 shows the actual vehicle test result when thrust absorption control is implemented.

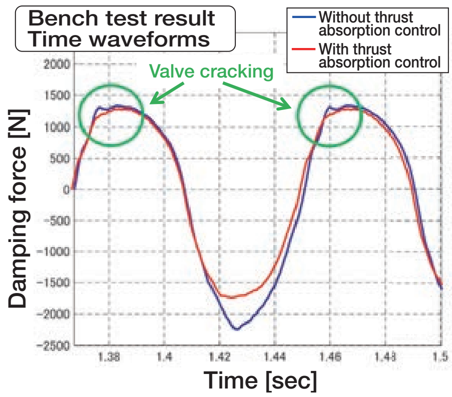

Fig. 8 Bench test result for thrust absorption control for the damper alone

The timing in which the damping force waveform distorts due to valve cracking is slightly after the positive/negative switch of the damper velocity. Upon this, the greater the damping force is, the more sudden the damping force change is. Therefore, considering the damper response delay, the current command is lowered around the damper velocity of 0. This can reduce the sudden change in the damping force, absorbing the thrust feel and improving the comfort.

In addition, as Fig. 9 shows, there is correlation between the movements of the sprung mass acceleration (accelerator sensor detection) and damper velocity (stroke volume derivative). Due to this, the thrust absorption control was implemented with the sprung mass acceleration when the stroke sensors were reduced.

In addition, current commands without thrust absorption control are difficult to identify due to noises, but they are close to consistent.

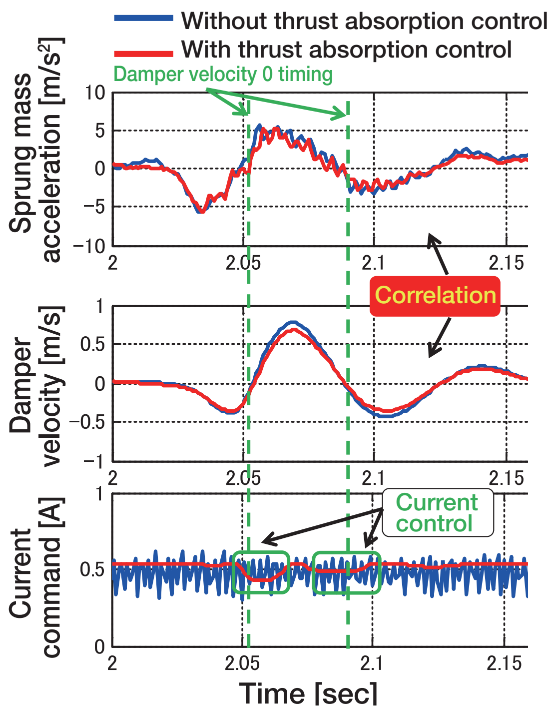

Fig. 9 Actual vehicle test result for thrust absorption control

4 Sensory Evaluation with an Actual Vehicle

We performed a sensory evaluation based on the internal evaluation criteria by installing the control, which was mentioned in the previous chapter, on an actual vehicle. Prior to performing the evaluation, we picked up items that contribute more to comfort and stable driving performance among the actual vehicle sensory evaluation items, as shown below. Each item was scored for the comfort and stable driving performance.

Comfort score: "Flat feel" + "Harshness*"

Stable driving performance score: "Grounded feel" + "Yaw/roll feel"

*Refer to Glossary "Harshness" on P. 34

In addition, the evaluation was conducted with the control of comfort-oriented specifications with 3 sensors as the standard. The sum of the comfort score and stable driving performance score is used as the definition of vehicle performance.

Fig. 10 shows the sensory evaluation result using an actual vehicle. "Standard vehicle" in Fig. 10 refers to the commercial vehicle, which was used in this control development. The control is provided through the standard semi-active damper and control algorithm (manufactured by another manufacturer/7 sensors). This vehicle was used for the internal evaluation to obtain the reference values and is therefore included in the figure. In addition, the standard vehicle also comes with 2 modes of comfort-oriented control and stable driving performance-oriented control.

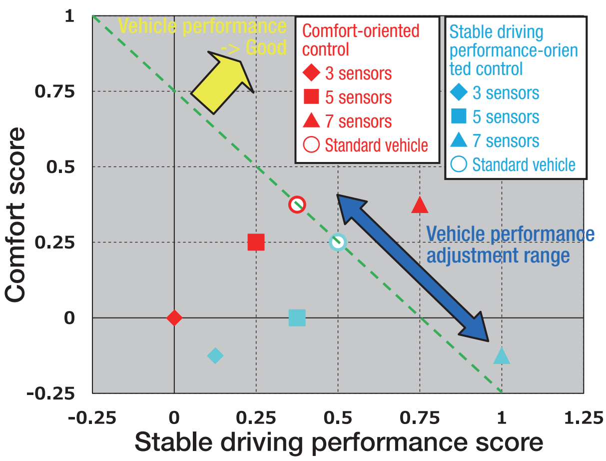

Fig. 10 Actual vehicle sensory evaluation result

The green broken line in Fig. 10 is a line that connects the scores for comfort-oriented control and stable driving performance-oriented control of the standard vehicle.

Generally, when turning is performed solely with control gain, the comfort and stable driving performance contradict each other. Due to this, the vehicle performance would change as if to move over the green broken line in case of the standard vehicle.

On the other hand, by tuning both the control algorithm itself and the control gain, the tuning flexibility increases. With less contradictions, this method realizes vehicle performance that especially focuses on comfort and stable driving performance. While it is unclear whether or not the standard vehicle's tuning is solely through the control gain, our scores for both comfort-oriented control and stable driving performance-oriented control were on the right side of the green broken line connecting the 2 scores of the standard vehicle, both cases using 7 sensors. This demonstrated that the vehicle performance is tuned at a high level.

In terms of stable driving performance-oriented control with 7 sensors, the road follow-up control (indicated in Table 1) is highly effective. We were able to tune the stable driving performance to the level in which the comfort deterioration from poor road rolling conditions was acceptable. Due to this, the comfort score was lower than that with 5 sensors, but we were ultimately able to greatly change the adjustment range of the vehicle performance.

5 In Closing

We have been able to change the vehicle properties focusing on stable driving and focusing on comfort with each number of sensors. We were able to achieve suitable control for each number of sensors as well as a wide range of vehicle performance adjustments.

Also with 3 sensors and 5 sensors, we think it is necessary to work on the development of even better control by comparing with vehicles that are controlled with the same numbers of sensors.

This report introduced our efforts to change the number of sensors for semi-active damper control, but we will also continue developing the technology to provide the control of both sprung mass and unsprung mass without newly adding sensors for semi-active damper control.

Finally, I would like to express my sincere gratitude for everyone in the relevant departments who have provided support in this development.

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Joined the company in 2012.
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