

Sensor Calibration Technique and Check Method for Active Damper System

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ABSTRACT

An active damper system is an electronically controlled damping force suspension system. Technology for calibrating the sensor of this system and a method of checking its operation were developed. The wheel stroke position is calibrated when the wheels are moved up and down by driving the vehicle over a bump, and the operation of the sensors is checked simultaneously. The sensors were calibrated and their operations were checked within a few seconds without the need of any dedicated equipment.

1. Introduction

An active damper system (ADS) is an electronically controlled damping force suspension system, which satisfies riding comfort and also keeps the flat feeling of the vehicle posture (Fig. 1).

Generally, calibration of the sensors is necessary for an electronically controlled system after the vehicle is assembled. Also, the system operation is checked before shipment to help preventing a system malfunction from occurring after shipment.

However, if large equipment is used to calibrate the sensors and check the operation of the system, the manufacturing cost will be higher because the working time for one vehicle tends to be longer.

As same as other electronically controlled systems, it is necessary for the ADS that the sensors should be calibrated and their operation checked. Technology for completing this in a short time, without using any dedicated equipment, was developed and is described in this paper.

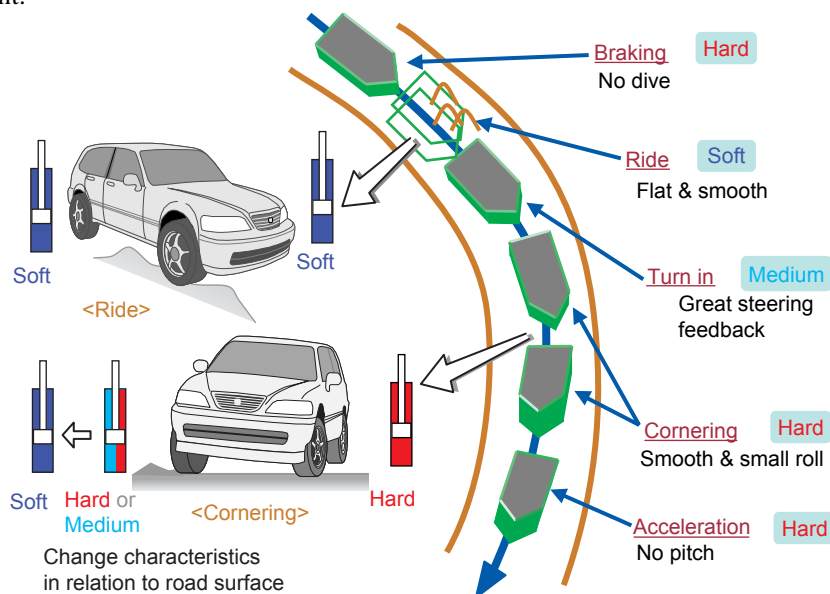


Fig. 1 Active damper system overview

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2. Outline of the ADS

The ADS controls the damping force of the suspension damper according to the differential of the longitudinal acceleration of the vehicle, and suppresses the pitching phenomenon whereby the front of the vehicle falls during braking and rises during acceleration. Likewise, the damping force of the damper is controlled according to the differential of the lateral acceleration of the vehicle, and suppresses the change in posture whereby the vehicle leans when turning or changing lanes⁽¹⁾. The ADS also reduces the vehicle vertical velocity that is generated by an uneven road surface.

When controlling the damping force of the damper, it is necessary to accurately detect the tension and compression velocity of the suspension, that is, the time change of the wheel stroke position. Enhancement of the mounting accuracy of the stroke sensors that detect the wheel stroke and suspension parts was studied to increase the damping force control performance.

The stroke sensor is a rotation angle sensor that detects the wheel stroke position as a link angle, converts the angle into voltage, and outputs it. To accurately detect the wheel stroke position, it was decided that after assembling the vehicle at the factory, the output from the stroke sensors at the position where the suspension is fully tensioned is calibrated.

Also, in the case of an electronically controlled system such as an ADS, the system is checked to ensure that it is operating normally, after the vehicle is assembled. The operation of the system of the vertical acceleration sensors and stroke sensors shown in Fig. 2 can be checked when the vehicle is moving up and down. Accordingly, by moving the vehicle up and down, the operation check of the vertical acceleration sensors and stroke sensors in conjunction with the calibration of the stroke sensors was studied.

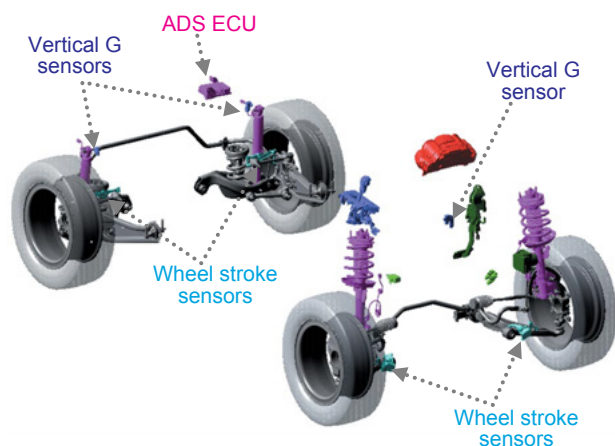


Fig. 2 ADS ECU and sensors

3. Stroke Sensor Calibration Technology

The following three methods of tensioning the suspension are used to calibrate the stroke sensors.

- (1) Raise the jack-up point underneath the vehicle.
It is necessary to use a hydraulically operated lift equipment of the type used for replacing four tires simultaneously. The vehicle is raised slowly, so checking the operation of the vertical acceleration sensors is a challenging task.
- (2) Use an excitation equipment that lifts up the wheels sharply. As the equipment moves the wheels up and down stably according to a program, the stroke sensors can be calibrated and the operation of the vertical acceleration sensors can be checked simultaneously. However, the equipment is expensive.
- (3) Drive the vehicle over a bump to move the wheels up and down. No additional equipment is necessary for this method and so it is inexpensive; the operation of the vertical acceleration sensors can also be checked simultaneously.

By comparing the above methods, it was decided to study the method of passing over a bump, which does not call for any equipment. In this concrete method, when the vehicle is driven over a bump, the wheel stroke of the suspension is fully tensioned, and the ADS electronic control unit memorizes the position where the suspension is maximally tensioned. Considering the situation that the workers drive a vehicle in various ways, the suspension should be stably tensioned at a wide range of vehicle speeds to establish this bump passing method.

3.1. Simulation Study

Figure 4 shows the results of simulating the wheel stroke change in this case that only a single frequency is contained in the height transition of the road surface when the vehicle is passing over a bump as shown in Fig. 3.

In the case of a single frequency in the height transition of the road surface, the range of the wheel stroke suspension displacement changes according to the vehicle speed. The bump to maintain the constant range of the suspension displacement at a wide range of vehicle speed is ideal. If the frequency contained in the bump height transition coincides with the sprung mass resonance frequency (1.3 Hz in the example described here), the height transition on the sprung mass and the wheel stroke change of the suspension can be stabilized to constant values with respect to the bump height. Consequently, a sweeping frequency bump (Fig. 5) where frequencies from lower than the sprung mass resonance frequency (1.3 Hz) to higher were swept and included in the bump height transition was devised. It was confirmed by simulation that the sweeping frequency bump was able to tension the suspension stably at a wide range of vehicle speeds compared to the case where the bump has only a single height frequency (Fig. 6).

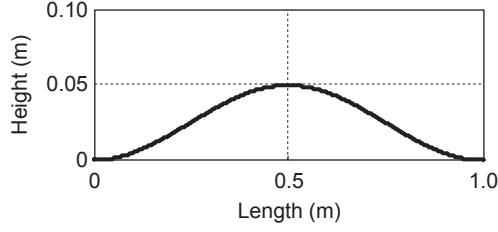


Fig. 3 Single frequency bump shape

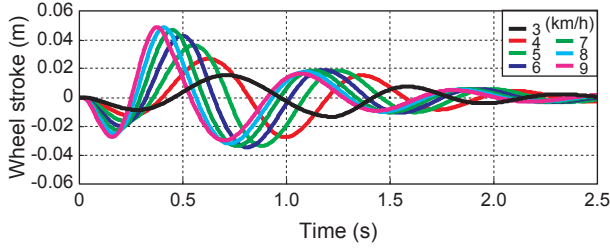


Fig. 4 Wheel stroke through single frequency bump (Simulation result)

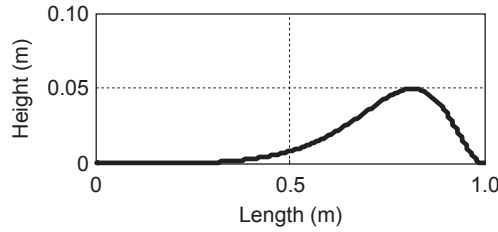


Fig. 5 Sweeping frequency bump shape

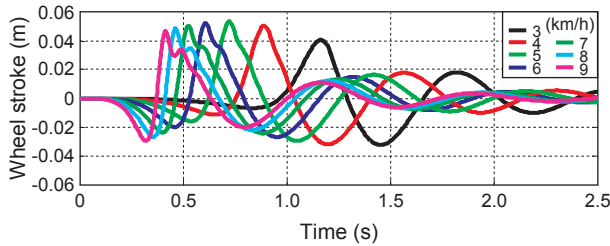


Fig. 6 Wheel stroke through sweeping frequency bump (Simulation result)

3.2. Study Using Actual Vehicle

A sweeping frequency bump was fabricated. And Fig. 7 shows the calibration results of the positions where the wheel stroke of the suspension is fully tensioned using the ADS electronic control unit as changing the vehicle speed when passing over the bump.

The numerical values measured when the vehicle is jacked up to tension the wheel stroke were almost equal to the numerical values calibrated by the electronic control unit when the vehicle was passing over a bump in the vehicle speed range between 7 and 15 km/h.

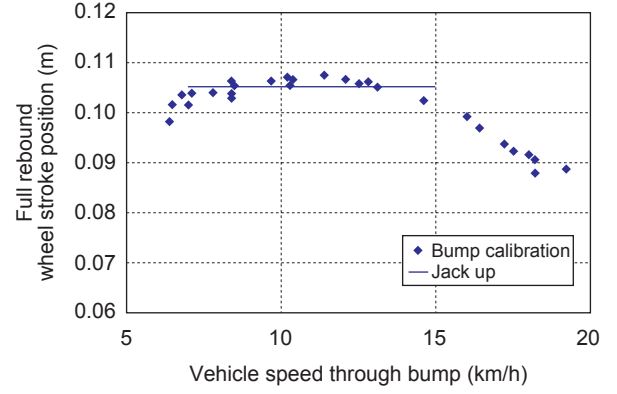


Fig. 7 Full rebound calibration result through sweeping frequency bump

The necessary time to pass over the bump is within a few seconds, and the stroke sensors can be calibrated in a short time. This method also has the advantage of enabling the operation of the stroke and vertical acceleration sensors to be checked, as described in the following section.

4. Sensor Operation Check Method

To confirm that the sensors are functioning normally, a mutual comparison of the stroke sensors and vertical acceleration sensors was performed when the vehicle passed over the bump. The wheel stroke and vertical acceleration were converted into sprung mass vertical velocity which is the same physical quantity (Fig. 8). The band-pass filter is effective in extracting the sprung mass resonance frequency and canceling the offset value of the sensors.

If the frequency contained in the height transition of the road surface when the vehicle is passing over the bump is lower than the sprung mass resonance frequency, the sprung mass vertical velocity is generated, but stroking ceases to occur. And at frequencies that are higher than the sprung mass resonance frequency, stroking occurs, but the sprung mass vertical velocity decreases. In order to move both the stroke displacement and sprung mass height transition with good balance, the bump should be set to

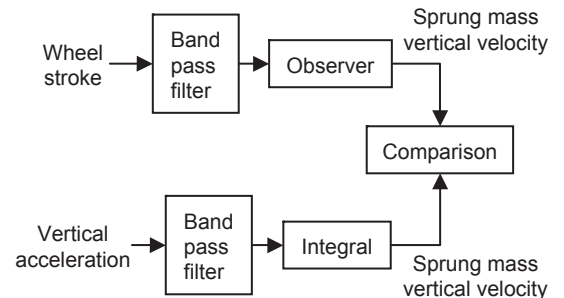


Fig. 8 Sensor comparison checking method

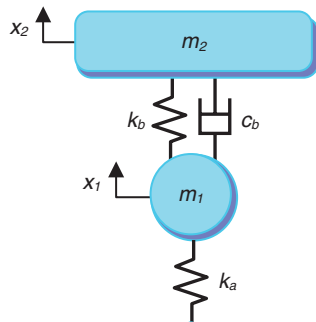
move the tires up and down at the sprung mass resonance frequency. A sweeping frequency bump enables the sprung mass resonance frequency to be included in the bump height transition at a wide range of vehicle speeds, so it is suitable in performing a mutual comparison of the stroke sensors and vertical acceleration sensors.

The sprung mass vertical velocity is obtained by integrating the vertical acceleration. To obtain the sprung mass vertical velocity from the stroke sensors, an observer of modern control theory (Fig. 10) was configured in the states where x_1 and the first order differential of x_1 , and x_2 and the first order differential of x_2 with respect to the suspension model (Fig. 9) which consists of the sprung mass and unsprung mass⁽²⁾.

The equations of motion for the suspension model are Eqs. (1) and (2).

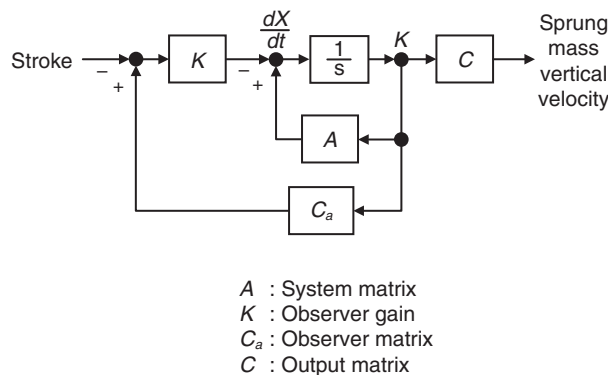
$$m_1 d^2 x_1 / dt^2 = k_b (x_2 - x_1) - k_a x_1 + c_b (dx_2 / dt - dx_1 / dt) \quad (1)$$

$$m_2 d^2 x_2 / dt^2 = k_b (x_1 - x_2) + c_b (dx_1 / dt - dx_2 / dt) \quad (2)$$



m_1 : Unsprung mass
 m_2 : Sprung mass
 k_a : Tire vertical stiffness
 k_b : Suspension stiffness
 c_b : Suspension damping coefficient
 x_1 : Unsprung mass vertical position
 x_2 : Sprung mass vertical position

Fig. 9 Suspension model



A : System matrix
 K : Observer gain
 C_a : Observer matrix
 C : Output matrix

Fig. 10 Observer

Figure 11 shows the results of that the electronic control unit of ADS calculates the vertical velocity of the vehicle from the output signals of the vertical acceleration sensors and stroke sensors when the vehicle passes over the bump.

Malfunctions in the sensor output gain can be found by performing a mutual comparison of the vertical velocity of the vehicle. Figure 12 shows the calculated results of the vehicle vertical velocity in the case where the gain dropped due to a breakdown in the signal output circuit of the stroke sensor.

Malfunctions in the sensor output gain can be judged by the four vertical velocities of the right and left stroke sensors and right and left vertical acceleration sensors. The right and left wheels pass over the bump at the same time, so the four vertical velocities should be the same. Compare the time integral of the absolute value of the vertical velocity obtained from the right stroke sensor whose output gain has fallen with the mean value of the time integral of the absolute values of the vertical velocity obtained from the other three sensors to judge the gain malfunction. When two sensors are compared for one wheel, malfunctions in the output gain can be judged, however, the malfunctioning sensor cannot be determined. The four sensors are compared by the right and left

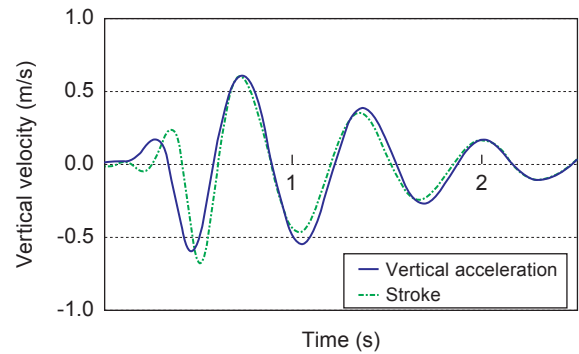


Fig. 11 Sprung mass vertical velocity comparison through bump

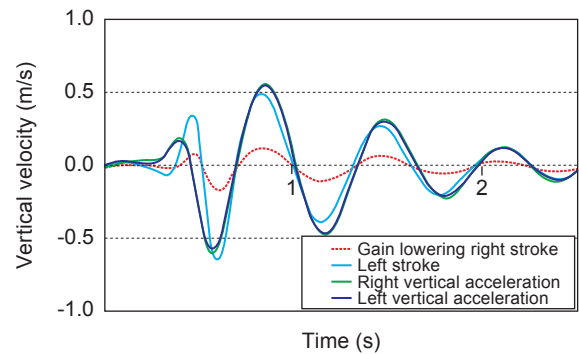


Fig. 12 Sensor gain lowering in sprung mass vertical velocity comparison

wheels, therefore, the sensor with the malfunctioning output gain can be determined by majority rule.

As a result of the above mutual sensor comparison technology, the operation of the sensors can be checked quantitatively without relying on the sensory evaluation by the workers.

5. Case of Application

A case in which this technology was used in the actual process is described here. The worker drives the vehicle and stops momentarily before the bump (Fig. 13). Then the worker starts the inspection using a shipping inspection tester (Fig. 14) and passes over the bump. The electronic control unit of the ADS memorizes the position where the wheel stroke is fully tensioned, simultaneously compares the stroke sensors and vertical acceleration sensors mutually, and sends the results thereof to the shipping inspection tester. Only the bump and software of the electronic control unit are enough to calibrate the stroke sensors and to mutually compare the sensors, so it is possible to dispense with dedicated equipment in this process.

By changing the length of the bump, the speed to pass over the bump can be adjusted. The passing speed of the vehicle driven by a worker at the bump location should be investigated, and the length of the bump should be



Fig. 13 Sweeping frequency bump in vehicle build plant



Fig. 14 Shipping inspection tester

adjusted accordingly. Honda of Canada Manufacturing, which established this process, set the bump passing speed to between 7 and 15 km/h. To reduce the bump passing speed, shorten the length of the bump. As an example, the length of the bump shortened by 40% reduced the passing speed to between 4 and 9 km/h.

6. Conclusion

Sensor calibration technology and a method of checking sensor operation were developed for vehicles equipped with an active damper system.

- (1) In the applied case of this technology, the worker drives the vehicle over a sweeping frequency bump. When the vehicle passes over the bump, the electronic control unit of the ADS runs a software program to calibrate the sensors and check the sensor operation.
- (2) The suspension was tensioned stably at a wide range of bump passing vehicle speeds. The output of the stroke sensor at the position where the suspension was fully tensioned was calibrated, thus the damping force control performance was enhanced.
- (3) When the vehicle was passing over the bump, the outputs of the stroke sensors and vertical acceleration sensors were converted into the sprung mass vertical velocity which is the same physical quantity, and mutually compared. The operation of the sensors can be checked quantitatively without relying on the sensory evaluation of the workers.
- (4) The sensor calibration and the sensor operation check were completed in a few seconds without the need of any additional large equipment.

References

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