

Study of Observer Considering Damper Force Dynamics for Semi Active Suspension Systems

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ABSTRACT

This paper reports that estimation accuracy of suspension stroke velocity is increased by considering the damping force delay characteristics to an observer. Thereby ride comfort is improved, using the simple and low-cost semi active suspension systems that use only three vertical acceleration sensors.

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INTRODUCTION

In recent years, energy-saving and low-cost semi active suspension systems that provide both comfortable ride quality and steering stability in cars have become commonplace. Various studies, such as skyhook control [1], have been done on controlling the ride comfort for semi active suspension systems. However, it has become necessary to estimate the stroke velocity in semi active suspension systems that control the damping force. Various methods have been examined with regards to estimating the stroke velocity. Apart from the sprung vertical acceleration sensor used for ride comfort control, research has also been done on the estimation of stroke velocity using stroke sensor [2] or stroke sensor and unsprung vertical acceleration sensor [3]. However, in order to develop simpler and lower-cost semi active suspension systems, it is necessary to develop observers that estimate stroke velocity using sprung vertical acceleration sensors used in ride comfort control.

The purpose of this paper is to improve the estimation accuracy of the observer that estimates the stroke velocity using the sprung acceleration sensor. Based on research done to date, the effectiveness of considering the non-linear characteristics of semi active damper in the observer model and of carrying out observer gain scheduling has been confirmed [4]. As a result, estimation in the vicinity of sprung resonance (approximately 1 [Hz]) is possible. However, when travelling on a complex road surface with a variety of frequencies, at least it is necessary to estimate close to the unsprung resonance frequency (approximately 10 [Hz]) in order to control the damping

force. Because semi active dampers are installed between body and wheel, and damping force is generated by the relative (stroke) velocity. So damping force has two resonance frequency points. Therefore, to control the damping force, at least it is necessary to estimate the stroke velocity beyond the higher resonance point (10 [Hz]). However, as the frequency increases, the estimation accuracy of the stroke velocity reduces. This is due to errors in the model, such as friction of suspension, bound stopper, and delay of damping force, and computation cycles. In order to resolve this issue, this paper proposes a practical observer model that has two new characteristics. Firstly, it considers the dynamic characteristics of the damping force. Secondly, it makes the dynamic characteristics to vary depending on control signals used. Moreover, we designed a highly accurate and practical observer by developing a suitable computation cycle. As a result, the estimation accuracy of the stroke velocity close to the unsprung resonance frequency and the ride comfort in an observer that used a sprung vertical acceleration sensor has been confirmed to improve.

SYSTEM OUTLINE

System Components

The system structure of the semi active suspension system used in the actual vehicle verification tests for this paper is shown in [Figure 1](#). Three sprung vertical acceleration sensors have been mounted. Based on the signals from these sensors, the ECU (Electric Control Unit) calculates the estimated stroke velocity and target damping force and adjusts the damping force of each semi active damper.

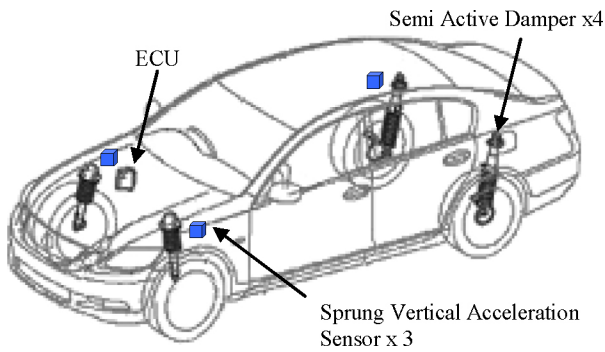


Figure 1. Semi active suspension system

The damping force adjuster for the semi active damper is composed of a linear solenoid and has a characteristic where the damping force increases in proportion to the control current i . Using stroke velocity v , the damping force characteristics f_c of the semi active damper can be expressed as the below equation.

$$f_c = F_d(v, i) \quad (1)$$

$F_d(v, i)$ is stored in the ECU as a data map. It outputs the damping force that is produced in the semi active damper when the control current i is conducted through the linear solenoid and stroke velocity v . Figure 2 shows the data map of the characteristics of the damping force $F_d(v, i)$ of the semi active damper.

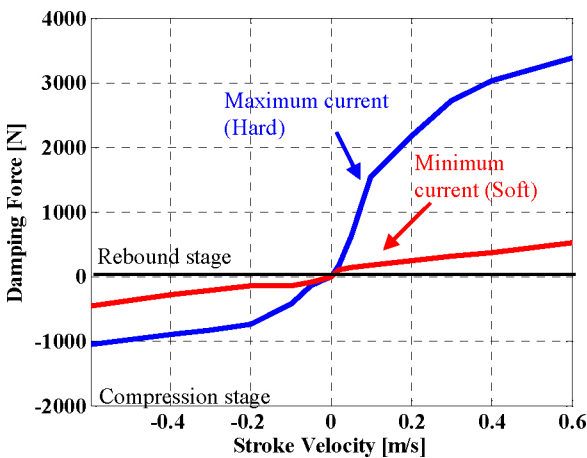


Figure 2. Characteristics of semi active damper

General Control Flow

Figure 3 shows the control flow, from the measurement of the state quantity by the sprung vertical acceleration sensor to the instruction of control current to the semi active damper. First of all, from the three sprung vertical acceleration sensors, the vehicle is regarded as a rigid body to obtain the sprung vertical acceleration at the wheel position of each wheel. Next, the stroke velocity estimation is done according to the observer using the sprung vertical acceleration of each wheel converted to its wheel position and the electric current i . Then, using the stroke velocity estimated by the observer and sprung vertical acceleration, the target damping force is calculated based on the non-linear H_∞ controller and the control current i is found.

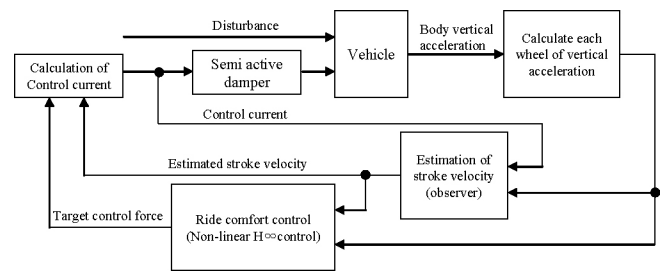


Figure 3. General control flow

Modeling

The single suspension model (2 degrees of freedom) this paper uses is shown in Figure 4.

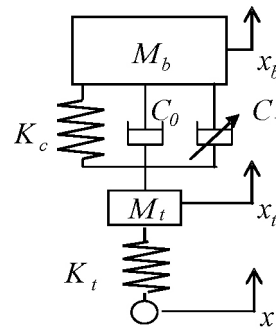


Figure 4. Single suspension model (2 degrees of freedom)

- M_b : Body Mass
- M_t : Wheel Mass
- K_c : Suspension Stiffness
- K_t : Tire Vertical Stiffness
- C_0 : Linear Damping Coefficient
- C_v : Variable Damping Coefficient
- x_b : Body Displacement
- x_t : Wheel Displacement
- x_r : Road Profile

ESTIMATION OF STROKE VELOCITY

The conventional observer that estimates the stroke velocity from sprung acceleration performs the estimation only around 1 [Hz] of the sprung resonance vicinity. If the unsprung body resonates when travelling on complex road surfaces, the estimation accuracy of the stroke velocity is reduced.

Thus, this paper aims to improve the ride comfort on complex road surfaces by improving the observer estimation accuracy up to 10 [Hz] of the unsprung resonance vicinity. Therefore, it is assumed that the target estimation accuracy is 1 - 10 [Hz] and the phase difference between the true value and the estimated stroke velocity is within ± 45 [deg]. The observer structure is shown in Figure 5.