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Mechanical Systems and Signal Processing 20 (2006) 373–388
Mechanical Systems and Signal Processing
www.elsevier.com/locate/jnlabr/ymssp

# Simulation and experimental validation of vehicle dynamic characteristics for displacement-sensitive shock absorber using fluid-flow modelling

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Received 23 February 2004; received in revised form 27 August 2004; accepted 27 September 2004
Available online 11 November 2004

**Abstract**

In this study, a new mathematical dynamic model of shock absorber is proposed to predict the dynamic characteristics of an automotive system. The performance of shock absorber is directly related to the car behaviours and performance, both for handling and ride comfort. Damping characteristics of automotive can be analysed by considering the performance of displacement-sensitive shock absorber (DSSA) for the ride comfort. The proposed model of the DSSA is considered as two modes of damping force (i.e. soft and hard) according to the position of piston. For the simulation validation of vehicle-dynamic characteristics, the DSSA is mathematically modelled by considering the fluid flow in chamber and valve in accordance with the hard, transient and soft zone. And the vehicle dynamic characteristic of the DSSA is analysed using quarter car model. To show the effectiveness of the proposed damper, the analysed results of damping characteristics were compared with the experimental results, which showed similar behaviour with the corresponding experimental one. The simulation results of frequency response are compared with the ones of passive shock absorber. From the simulation results of the DSSA, it can be concluded that the ride comfort of the DSSA increased at the low-amplitude road condition and the driving safety was increased partially at the high-amplitude road condition. The results reported herein will provide a better

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0888-3270/$ - see front matter 
doi:10.1016/j.ymssp.2004.09.006

understanding of the shock absorber. Moreover, it is believed that those properties of the results can be utilised in the dynamic design of the automotive system.


*Keywords:* Shock absorber; Damping force; Quarter car model; Vehicle vibration; Ride comfort; Displacement sensitive; Body valve

## 1. Introduction

Shock absorber is an important part of automotive which has an effect on ride characteristics such as ride comfort and driving safety. There are several kinds of automotive shock dampers such as position-sensitive damping, acceleration-sensitive damping, and continuous damping control. Displacement-sensitive shock absorber (DSSA), which is also called stroke-dependent shock absorber, and has a similar structure compared with conventional passive shock absorber. Nevertheless, the DSSA has additional flow passages such as displacement-sensitive orifice at the cylinder wall. The DSSA has two modes of damping force according to piston stroke.

When piston stroke is in the range of displacement-sensitive orifice, the leakage occurs through this orifice. In this range, the damping force become low compared with the passive shock absorber. On the other hand, when the piston stroke is out of range of displacement-sensitive orifice, leakage through the orifice is blocked. In this range, the damping force becomes high because of leakage block. Such a DSSA improves ride comfort on the paved road driving conditions because of low damping force caused by small piston stroke. Also, the driving safety is improved when the vehicle is driving on rough roads or bumper roads because of high damping force caused by large piston stroke and high-vibration amplitude. Accordingly, the DSSA can keep ride comfort and driving safety as well.

There have been several studies about shock absorber. At first, Lang [1] proposed simple mathematical model of passive shock absorber. After that many studies have been carried out to analyse the performance of shock absorber [2]. Cherng et al. [3] reported the effect of noise of shock absorber using acoustic index method. Koenraad [4] proposed a mathematical model of the mono-tube-type gas-charged shock absorber. Herr et al. [5] proposed a mathematical model of twin tube-type shock absorber. Simms et al. [6] investigated the influence of damper properties on luxury vehicle dynamic behaviour through the simulation and test. Liu et al. [7] reported the characteristics of non-linear dynamic response for the twin-tube hydraulic shock absorber by using a software programme. Nevertheless, there have been few studies carried out on the DSSA. Recently, there has been a study reported on the DSSA [8]. In those studies [9], the transient characteristics of displacement-sensitive orifice were not considered and the performance of the vehicle with the DSSA was not verified. In general, those studies are insufficient to understand the dynamic characteristics of DSSA completely to judge the handling and ride comfort of automotive.

Therefore, in this study a new mathematical and simulation model of the DSSA is proposed and analysed, which considered the transient range of displacement-sensitive orifice of the DSSA. And the vehicle dynamic characteristics of the proposed model are evaluated in the time and frequency domain using quarter car-simulation model. The results of the dynamic characteristics