STUDY ON CONTROL OF BUS-SUSPENSION SYSTEM

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Abstract

In this study, a PID controller is used to control active suspension of a quarter-bus model. The displacement is applied to be an input to PID controller while active forces, improving ride comfort and handling properties are the controller outputs. The response of the system using the PID controller is then compared with those of proposed fuzzy logic controller. The percentage of overshoot is about 10% of the input's amplitude (less than maximum requirement of about 20%), and settling time is 2 seconds less than 5 seconds (not exceed the minimum requirement). The performance of optimized bus-suspension system is improved.

Keywords: Bus suspension, PID, control, optimization, fuzzy

1. Introduction

Nowadays, a struggling race is taking place among the automotive industry so as to produce highly developed models. One of the performance requirements is advanced suspension systems which prevent the road disturbances to affect the passenger comfort while increasing riding capabilities and performing a smooth drive.

Many control methods have been proposed to overcome these suspension problems. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body when road disturbances from smooth road and real road roughness which is using a fuzzy control algorithm [1]. Many active suspension control approaches such as Linear Quadratic Gaussian (LQG) control, adaptive control, and nonlinear control are developed and proposed so as to manage the occurring problems [2-4].

Among the recent nonlinear control methods, fuzzy control methods grab nowadays the attention of many researchers. A fuzzy model has excellent capability in a nonlinear system description and is particularly suitable for the complex and uncertain systems [5]. While there are various fuzzy modelling methods, Sugeno's fuzzy models have been extensively studied up to now because the fuzzy model can represent a nonlinear equation in spite of a small number of rules and be incorporated with the conventional control methods easily.

During the last decades fuzzy logic has implemented very fast hence the first paper in fuzzy set theory, which is now considered to be the seminal paper of the subject, was written by Zadeh [6], who is considered the founding father of thefield. Then in 1975, Mamdani, developed Zadeh`s work and demonstrated the viability of Fuzzy Logic Control FLC) for a small model steam engine.

Støíbrskýl et al [7], studied on fuzzy logic control of active suspension of a one-half-car model. It is aimed to minimize chassis and wheels deflection when road surfaces, pavements are acting on the tires of running cars. Huang and Lin [8], have studied on a quarter-car hydraulic suspension system to evaluate the performance of active vehicle suspension, and a self organizing fuzzy controller (SOFC) is used to control the position and acceleration oscillation amplitudes of the spring mass due to the rough road variation.

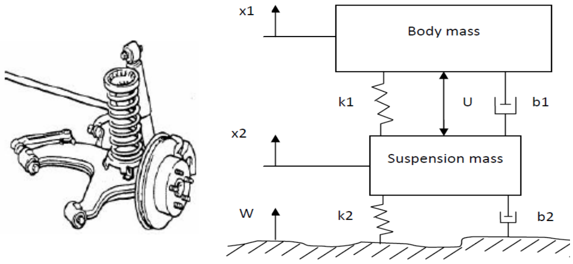

Figure 1. A quarter-bus (1/4) model

While the purpose of the suspension system is to provide a smooth ride in the car and to help maintain control of the vehicle over rough terrain or in case of sudden stops, increasing ride comfort results in larger suspension stroke and smaller damping in the wheel-hop mode. Designing an automatic suspension system for a bus turns out to be an interesting control problem.

When the suspension system is designed, a 1/4 bus model (quarter car model) is used to simplify the problem to a one dimensional spring-damper system. A diagram of this system is shown in Fig.1.

2. System design

A quarter-car model with two degrees of freedom is considered. This model uses a unit to create the control force between body mass and wheel mass. The following constants and variables for this study are shown in Table 1:

Table 1. Parameters

Parameters	Symbol	Quantities
▪ Body mass	m1	2500kg
▪ Suspension mass	m2	320kg
▪ Spring constant of suspension system	k1	80,000N/m
▪ Spring constant of wheel and tire	k2	500,000N/m
▪ Damping constant of suspension system	b1	350Ns/m
▪ Damping constant of wheel and tire	b2	15,020Ns/m
▪ Controller output (force)	u	-

A good bus suspension system should have satisfactory road holding ability, while still providing comfort when riding over bumps and holes in the road. When the bus is experiencing any road disturbance, the bus body should not have large oscillations, and the oscillations should dissipate quickly.

Since the distance **x1-W** is very difficult to measure, and the deformation of the tire (**x2-W**) is negligible, we will use the distance **x1-x2** instead of **x1-W** as the output in our problem. The road disturbance (**W**) in this problem will be simulated by a step input. This step could represent the bus coming out of pothole.

We want to design a feedback controller so that the output (**x1-x2**) has an overshoot less than 10% and a settling time shorter than 5 seconds. For example, when the bus runs onto a 10 cm high step, the bus body will oscillate within a range of +/- 5 mm and return to a smooth ride within 5 seconds.

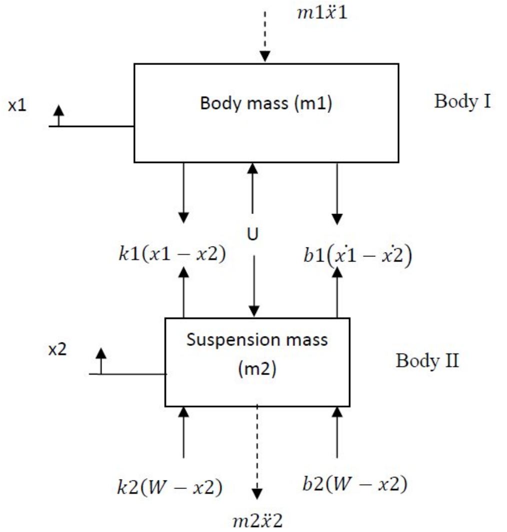

Figure 2. Free body diagram (FBD) of the system

Based on Newton's law and considering the input U(s) by W(s)=0, the dynamic equations of motion of the car body and the wheel are as follows (illustrated in Fig. 3):

$$G1(s)=\frac{X1(s)-X2(s)}{U(s)}=\frac{(m1+m2)s^2+b2s+k2}{\det[A]} \quad (1)$$

when we want to consider input U(s) only, we set W(s)=0. Thus we get the transfer function G1(s) as the following:

$$G2(s)=\frac{X1(s)-X2(s)}{W(s)}=\frac{-m1b2s^3-m1k2s^2}{\det[A]} \quad (2)$$

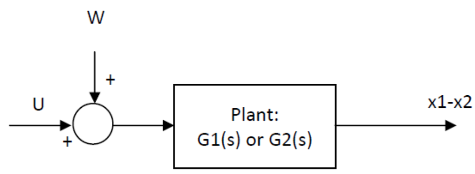

Figure 3. Bus-system block diagram without controller

To derive the dynamic equations of this system, Newton's 2nd law of motion is used, and the equations below are presented.

$$m_1\ddot{x}_1=-b_1(\dot{x}_1-\dot{x}_2)-k_1(x_1-x_2)+u \quad (3)$$

$$m_2\ddot{x}_2=-b_1(\dot{x}_1-\dot{x}_2)-k_1(x_1-x_2)+b_2(\dot{W}-\dot{x}_2)+k_2(W-x_2)-u \quad (4)$$

To transform the motion equations of the quarter-bus model into a state-space model, including variable

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vector, input vector and the disturbance vector is formed after some algebraic operations.

$$\dot{x} = Ax + BW$$
$$y = Cx + DW$$

$$\begin{bmatrix} \dot{X}_1 \\ \ddot{X}_1 \\ \dot{Y}_1 \\ \dot{Y}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{b_1 b_2}{m_1 m_2} & 0 & \frac{b_1}{m_1}\left(\frac{b_1}{m_1}+\frac{b_1}{m_2}+\frac{b_2}{m_2}\right)-\frac{k_1}{m_1} & -\frac{b_1}{m_1} \\ \frac{b_2}{m_2} & 0 & -\left(\frac{b_1}{m_1}+\frac{b_1}{m_2}+\frac{b_2}{m_2}\right) & 1 \\ \frac{k_2}{m_1} & 0 & -\left(\frac{k_1}{m_1}+\frac{k_1}{m_2}+\frac{k_2}{m_2}\right) & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ \dot{X}_1 \\ Y_1 \\ Y_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{m_1} & \frac{b_1 b_2}{m_1 m_2} \\ 0 & -\frac{b_2}{m_2} \\ \frac{1}{m_1}+\frac{1}{m2} & -\frac{k_2}{m_2} \end{bmatrix} \begin{bmatrix} U \\ W \end{bmatrix} \quad (5)$$

3. Controller schemes

Before the proposed controller methods are discussed, they are PID and Fuzzy, a default performance of the system will be observed by using a 0.1mm high step as the disturbance. Default performances are shown by Fig. 4, 5 and 6.

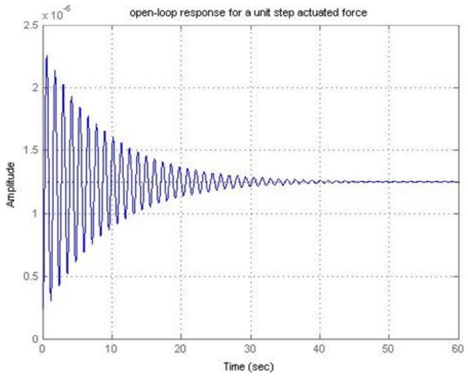

Figure 4. Unit step actuated force

From Fig. 4, we can see that the system is under-damped. The steady-state error is about 0.013 mm. Moreover, the bus takes very unacceptably long time for it to reach the steady state or the settling time is very large.

From Fig.5, we can see that when the bus passes a 10 cm high bump on the road, the bus body will oscillate for an unacceptably long time (100 seconds) with larger amplitude, 13 cm, than the initial impact. Large overshoot and the less settling time will cause damage to the suspension system.

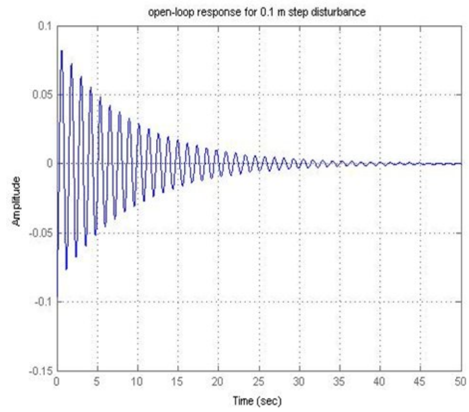

Figure 5. Unit step actuated force with 0.1mm disturbance

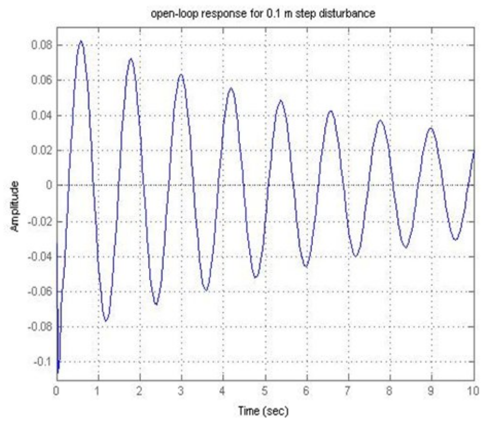

Figure 6. Unit step actuated force with 0.1mm disturbance (magnified 0-10 seconds)

3.1 PID controller

The transfer function of G1(s) and G2(s) can be formulated in following form:

$$G1(s) = \frac{numa}{dena} \quad \text{and}$$

$$G2(s) = \frac{numd}{dend}$$

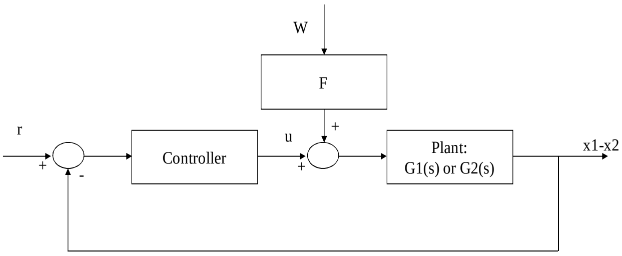

Figure 7. Schematic of common closed-loop control system

Fig. 7 shows the relation between the road disturbance (W) and the output (x1-x2) as follows:

$$\left[\frac{numf}{denf}W - \frac{numc}{denc}(x1-x2)\right]\frac{numa}{dena} = (x1-x2)$$

$$\left[\frac{numf}{denf}W - \frac{numc}{denc}(x1-x2)\right] = \frac{dena}{numa}(x1-x2)$$

$$\frac{numf}{denf}W = \left(\frac{dena}{numa} + \frac{numc}{denc}\right)(x1-x2)$$

$$\frac{(x1-x2)}{W} = \frac{numa \cdot numf \cdot denc}{denf\,(dena \cdot denc + numa \cdot numc)}$$

so,

$$numt = numa \cdot numf \cdot denc$$

$$dent = denf\,(dena \cdot denc + numa \cdot numc)$$

Recall the transfer function (TF) for Proportional-Integral-Derivative (PID) controller

$$K_P + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s}$$

where KP is proportional gain, KI is integral gain and KD is derivative gain for KP=200000, KI=800000 and KD=600000; will get the result

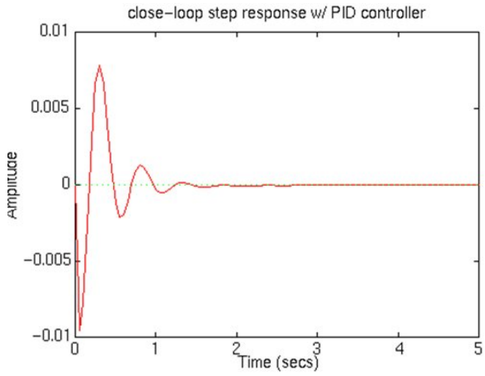

Figure 8. Response of PID controller

3.2 Other methods (Fuzzy)

In this study, a fuzzy control scheme is implemented to be compared with PID control scheme. The error signal, which is aimed to be minimized for a zero deflation level, is obtained as the difference between desired deflation and the bounce of auto or deflation from horizontal. The error and is one of the inputs to fuzzy controller. The other input is the change in this error. Error signal (e) is inputted to the controller to be minimized while the change in error signal is used by fuzzy controller to get information about speed and direction of the error in order to determine how fast and from which direction is the error approaching toward zero. The proposed fuzzy controller uses this information to result in the amount of increment; du. The process done by the fuzzy controller is depicted in Figure 9.

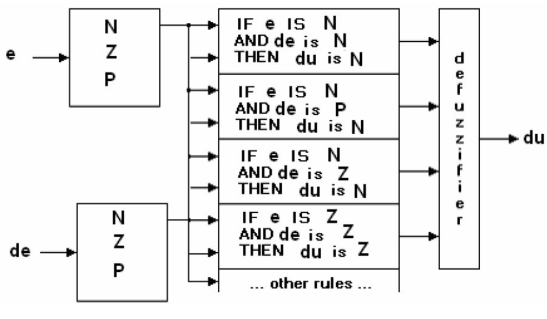

Figure 9. Fuzzy control system

The abbreviations used here correspond to N Z P (Negative Zero Positive). The control input given to the system is u(k), which is obtained by adding current increment du(k) to the previous value of the control input, u(k-1). This is nothing but implementing fuzzy controller to get an output effect similar to that of an integrator without any integrator present. The change du(k) in control input is equal to X1-X2, displacement of the tire taken as the output of the system.

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By implementing the fuzzy decision rules an appropriate output state is selected and assigned o a membership value. Then these truth values are defuzzified to yield the final crisp change du(k). For each sampling the output value will adjust the suspension system and then the control cycle will begin again to generate the next value. Result will be given as follows:

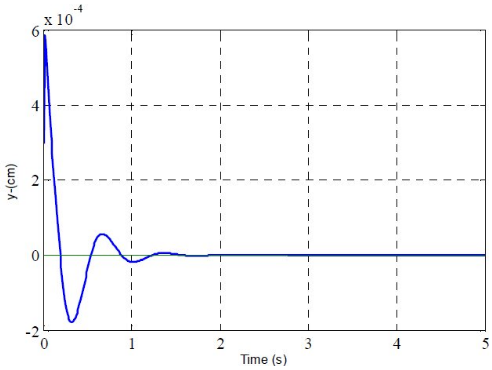

Figure 10. Response of fuzzy controller

4. Analysis and Discussion

Using a PID controller, the percentage of overshoot is about 10% of the input's amplitude (less than maximum requirement of about 20%), and settling time is 2 seconds less than 5 seconds (not exceed the minimum requirement).

The main difference between classical control systems and fuzzy control is with the classical mathematical methods it's difficult to model and control the complex systems but in fuzzy logic it's easier and flexible, there are not precise boundaries.

The fuzzy logic comprised of three principal components: a fuzzification interface, a knowledge base, and a defuzzification interface. The rule base used in the active suspension system for ¼ bus model consists of 9 rules with fuzzy terms. The output of the controller is a fuzzy set of control. For defuzzification, the method of 'center of gravity' is used here. A possible choice of the membership functions for the variables of the active suspension system represented by a fuzzy set is as follows:

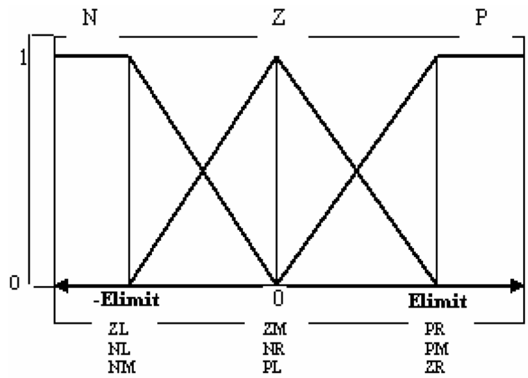

Figure 11. Triangular membership functions

The abbreviations used here correspond to:

- NL…..Negative Left
- NM…..Negative Medium
- NR……Negative Right
- ZL……Zero Left
- ZM…..Zero Medium
- ZR…..Zero Right
- PL……Positive Left
- PM…..Positive Medium
- PR……Positive Right

In Fig. 10 the fuzzy control response of the model with a 0.1 m step disturbance is given. The settling time is about 1.0 second. In order to get better views of both settling time and overshoot. As it can easily be seen from Fig. 10, the settling time has been reduced from 1.5 s to about 1.0 s, while the overshoot is reduced from 0.0048m down to 0.0006m.

5. Conclusion

In this study, a PID controller is used to control active suspension of a quarter-bus model. The displacement is applied to be an input to PID controller while active forces, improving ride comfort and handling properties are the controller outputs. The percentage of overshoot is about 10% of the input's amplitude (less than maximum requirement of about 20%), and settling time is 2 seconds less than 5 seconds (not exceed the minimum requirement). The performance of optimized bus-suspension system using PID controller is improved.

Meanwhile, a fuzzy logic based controller is designed and employed for controlling an active suspension system of a ¼ bus model. The proposed model is aimed to developed and carry the response of classical PID controller up to a comparable level. By using a nine-rule fuzzy rule base model with triangular fuzzy subsets, accepted improvements are obtained in both settling time and oscillation reductions. A 25-rule fuzzy controller could have given better results, however, increasing rule numbers is not preferable since the number of the rules affect the processing time of the fuzzy algorithm. In a controller point of view any time delay affecting the operation of the system and controller performance is not preferable. Therefore a nine-rule fuzzy controller is used due to the acceptable results.

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