Design and Simulation of Automatic Suspension Control System of the Four-Wheel Vehicle

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Abstract

One of parts from a vehicle to decrease vibration into a vehicle is suspension system. In general there are two parts like springs and dampers. Every vibration is caused the vehicle go through a road condition will be absorbed by the suspension system, so the vibration is not continually and stopped at the time. The most of standard suspension, which is used with two constant damper values, have not satisfactory road holding ability. One of way to guarantee providing comfort at many condition of road is to change dampers value as automatically. So the suspension system is called semi-active suspension. A good vehicle suspension system should have satisfactory road holding ability, while still providing comfort when riding over bumps and holes in the road. When the vehicle is experiencing any road disturbance (i.e., pot holes, cracks, and uneven pavement), the vehicle body should have not large oscillations, and the oscillations should dissipate quickly. Since the research is needed to make design of a vehicle suspension automatic control to change the value of dampers as automatically. To analyze feedback suspension control system it used state-space methods and the program of computer like Simulink from MATLAB. The simulation result shows that to get optimal performance of suspension, the value of dampers can be change from 100 Ns/m to 100,000 Ns/m. So, the vehicle always stable when it riding over bumps and holes in the road, because the oscillations response achieved at least 1 seconds and also overshoot max 5% from disturbances of road.

KEY WORDS: Dampers, automatic suspension control, feedback control.

Introduction

Since the development of technology that is human being oriented, the advance of the technology is developed not just for its main function but also for the user of the technology itself. Computability evaluation from the vehicle user is determined by the endurance of human to the acceleration, deceleration and vibration that occurs in the vehicle (Gopal, 1982).

One of the parts of the vehicle that could decrease the car vibration is suspension system. In generally there are two parts of the suspension system including springs and dampers. Every vibration that occurred when the vehicle go through a particular road condition will be dampered by the suspension system so that the vibration would not continuously occurs and will be ending at a certain time.

The suspension system that commonly applied on the vehicle is a passive suspension system in which its spring stiffness and dumping value is constant. In the passive suspension system it dumping system has not yet gives a high performance where its vibration amplitude still high and the time required terminating the vibration is quite longer. To overcome this condition, it is then introduced a semi-active suspension and active suspension system. Unfortunately the active suspension system requires larger energy and less economizly, so then the semi-active suspension become a better choice to keep the quality of the car comfortable on any road condition.

Regarding those condition, it could be written that the passive and active suspension system could not provide a satisfied driving to the automotive system, so then it is important to have study on the semi-active suspension system by building a mathematic model and its MATLAB simulation and designing one of the semi-active.

Methodology

Research procedures

The research procedure is shows in Figure 1.

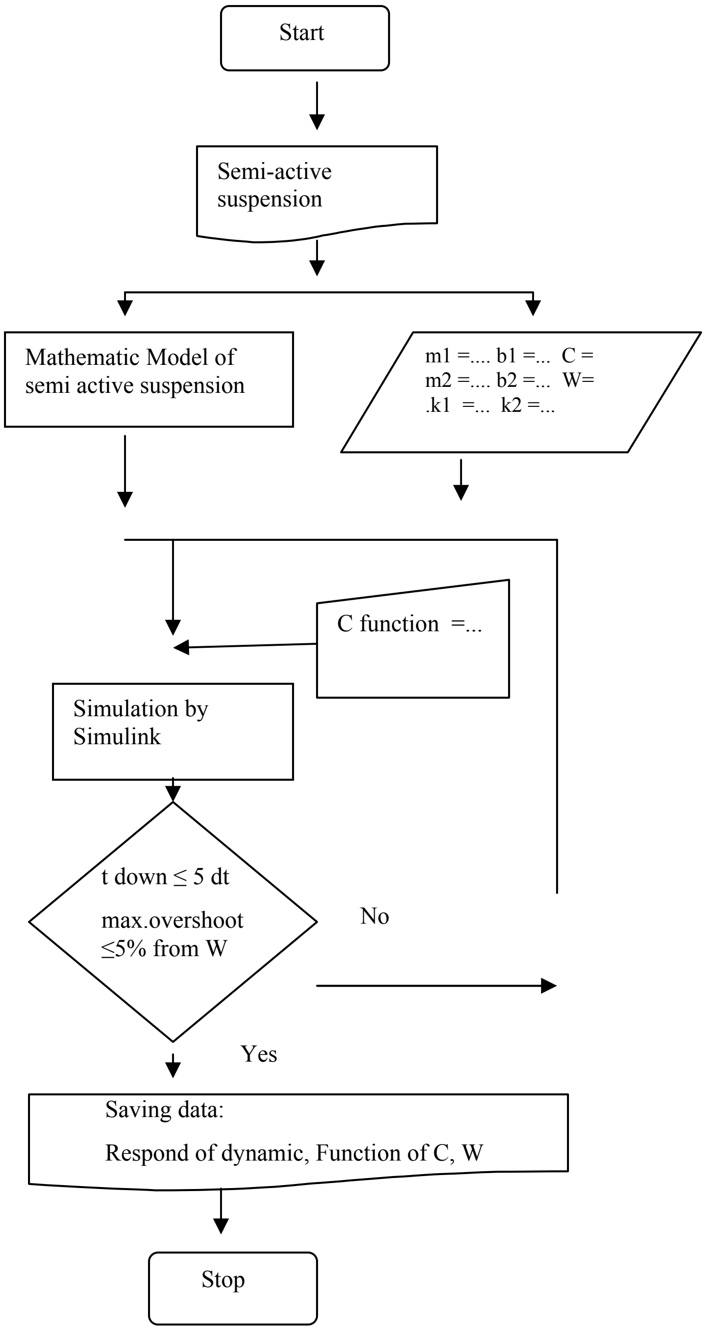

Figure 1: Flowchart simulation of data experiment.

Suspension vehicle Model (1/4 vehicle model) (Carnnie Mellon, 2004)

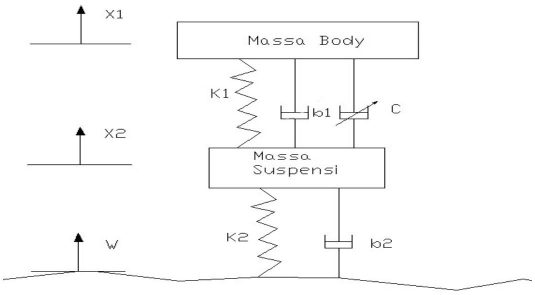

Figure 2: Modeling of suspension system in one of wheel.

Specification data of suspension system as:

- Mass of vehicle body (M1) = 2500 kg
- Mass of vehicle suspension (M2) = 320 kg
- Constant value of spring suspension (K1) = 80.000 Nm
- Constant value of spring from wheel (K2) = 500.000 Nm
- Constant value of damping wheel (b2) = 15.020 Ns/m
- Constant value of suspension damping system (b1) = 200 Ns/m
- Constant of value damping suspension (C) that dumping value can be arrange

Mechanical equation from Figure 2 and Newton's Law (Katsushiko, 1991), as it obtained the dynamic equation as follows:

$$M_1\ddot{x}_1 = -b_1(\dot{x}_1 - \dot{x}_2) - K(x_1 - x_2) - C(\dot{x}_1 - \dot{x}_2)\text{.......................}(1) \quad [1]$$

$$M_2\ddot{x}_2 = b_1(\dot{x}_1 - \dot{x}_2) + K(x_1 - x_2) + b_2(\dot{W} - \dot{x}_2) + K_2(W - x_2) + C(\dot{x}_1 - \dot{x}_2)\text{...}(2) \quad [2]$$

The design of semi-active suspension

Figure 3 shows that the design of semi active suspension system for a quarter of vehicle model is designed as follows:

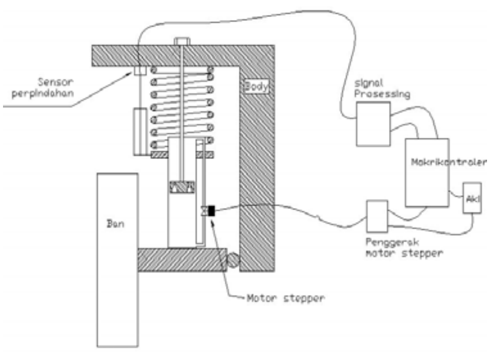

Figure 3: Prototype of semi active suspension system.

The large dumping is controlled by using a regulator valve which have the main function to control the fluid flows that caused by the up and down movement of the piston when there are a disturbance on the suspension system. A motor stepper has been used to operate the regulator valve, where the motor stepper receives an order from a micro-controller that control that fast and large the revolution required in order to get the expected dumping value

In the micro-controller, there will be a processing of the data that as been received from the displacement sensor. This sensor can produce a signal that represents the position change of the vehicle body to the tire. This signal then will be sent to the micro-controller to be processed, so then these processing results will be sent to the stepper motor to control the dumping, in order to keep the comfortable quality of the vehicle driver and passenger.

Modeling of semi-active suspension system

Design Requirements

The design requirement for a vehicle before, at the time and after experiencing disturbance including:

1. The body of vehicle before, at the time and after has experiencing a disturbance should be stand still.
2. If there are ossilations, it should be very small and quickly stopped. (When the vehicle runs onto a 10 cm high step, the vehicle body will oscillate within a range of +/- 5 mm and return to a smooth ride within 5 seconds).

Results and Discussions

Simulation of Model

It assumed that all initial condition is zero so that this equation describes when the vehicle wheel passes over bumps and holes in the road. Equations 1 and 2 could be represented into transfer function model by solving the Laplace Laplace transformation (Katsushiko, 1997) from the above equation.

$$(M_1 s^2 + b_1 s + K_1)X_1(s) - (b_1 s + K_1)X_2(s) = U(s)$$

$$-(b_1 s + K_1)X_1(s) + (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2))X_2(s) = (b_2 s + K_2)W(s) - U(s)$$

$$\begin{bmatrix} (M_1 s^2 + b_1 s + K_1) & -(b_1 s + K_1) \\ -(b_1 s + K_1) & (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2)) \end{bmatrix} \begin{bmatrix} X_1(s) \\ X_2(s) \end{bmatrix} = \begin{bmatrix} U(s) \\ (b_2 s + K_2)W(s) - U(s) \end{bmatrix}$$

$$A = \begin{bmatrix} (M_1 s^2 + b_1 s + K_1) & -(b_1 s + K_1) \\ -(b_1 s + K_1) & (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2)) \end{bmatrix}$$

$$\Delta = \det \begin{bmatrix} (M_1 s^2 + b_1 s + K_1) & -(b_1 s + K_1) \\ -(b_1 s + K_1) & (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2)) \end{bmatrix}$$

$$\text{or, } \Delta = (M_1 s^2 + b_1 s + K_1) \cdot (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2)) - (b_1 s + K_1) \cdot (b_1 s + K_1)$$

Solving inverse matrix of A and then multiply with input U(s) and W(s) on the right –hand side as follows:

$$\begin{bmatrix} X_1(s) \\ X_2(s) \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} (M_2 s^2 + (b_1 + b_2)s + (K_1 + K_2)) & (b_1 s + K_1) \\ (b_1 s + K_1) & (M_1 s^2 + b_1 s + K_1) \end{bmatrix} \begin{bmatrix} U(s) \\ (b_2 s + K_2)W(s) - U(s) \end{bmatrix}$$

$$\begin{bmatrix} X_1(s) \\ X_2(s) \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} (M_2 s^2 + b_2 s + K_2) & (b_1 b_2 s^2 + (b_1 K_2 + b_2 K_1)s + K_1 K_2) \\ -M_1 s^2 & (M_1 b_2 s^3 + (M_1 K_2 + b_1 b_2)s^2 + (b_1 K_2 + b_2 K_1)s + K_1 K_2) \end{bmatrix} \begin{bmatrix} U(s) \\ W(s) \end{bmatrix}$$

When the input is to be observed U(s), it assumed that the disturbance input W(s) =0. So then it can determine the transfer functionG1(s) as follows:

$$G_1(s) = \frac{X_1(s) - X_2(s)}{U(s)} = \frac{(M_1 + M_2)s^2 + b_2 s + K_2}{\Delta} \qquad [3]$$

When we want to observe the disturbance input W(s), we assume that the reference input U(s) =0. Until we can determine the transfer function G2(s) as follows:

$$G_2(s) = \frac{X_1(s) - X_2(s)}{W(s)} = \frac{-M_1 b_2 s^3 - M_1 K_2 s^2}{\Delta} \qquad [4]$$

The equation of linier differential from the dynamic system 1 and 2 are also can be solved by using state-space methods as follows:

$$\begin{bmatrix} X_1 \\ X_1 \\ Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{-b_1 b_2}{M_1 M_2} & 0 & \left(\frac{b_1}{M_1}\left(\frac{b_1}{M_1} + \frac{b_1}{M_2} + \frac{b_2}{M_2}\right) - \left(\frac{K_1}{M_1}\right)\right) & \frac{-b_1}{M_1} \\ \frac{b_2}{M_2} & 0 & -\left(\frac{b_1}{M_1} + \frac{b_1}{M_2} + \frac{b_2}{M_2}\right) & 1 \\ \frac{K_2}{M_2} & 0 & -\left(\frac{K_1}{M_1} + \frac{K_1}{M_2} + \frac{K_2}{M_2}\right) & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_1 \\ Y_1 \\ Y_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{M_1} & \frac{b_1 b_2}{M_1 M_2} \\ 0 & \frac{-b_2}{M_2} \\ \left(\frac{1}{M_1} + \frac{1}{M_2}\right) & \frac{-K_2}{M_2} \end{bmatrix} \begin{bmatrix} U \\ W \end{bmatrix} \qquad [5]$$

So the matrix output can be determined as follows:

$$Y = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X1 \\ X1 \\ Y_1 \\ Y_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \end{bmatrix} \begin{bmatrix} U \\ W \end{bmatrix} \qquad [6]$$

Analysis of simulation results

To design of suspension model in order to suit the requirement of design, it can be done by processing the simulation result data to produce the suspension model that suit the criteria of the design requirement by taking the data that resulted from simulation. These data can be processed to get the suspension model as it is planned.

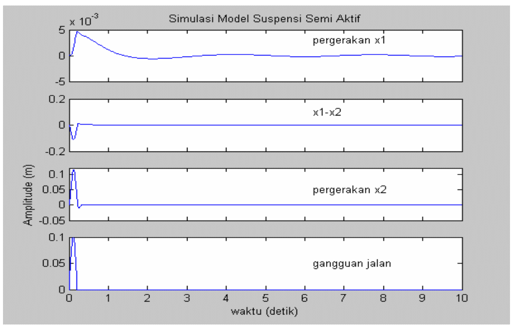

Figure 4: The simulation result for the semi-active suspension.

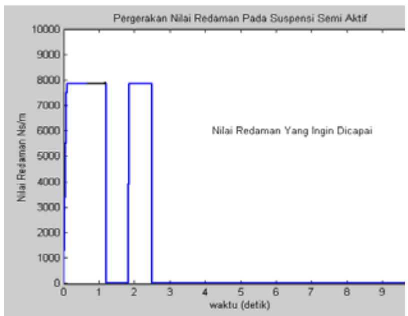

Figure 5: The Dumper value.

Based on the result of simulation by using Simulink MATLAB program, it is obtained that the suspension should have the value of damper, which can quickly change, refer to the large of the disturbance. Figure 4 shows the dumping value of suspension, it has obtained the design criteria. The damper value that should be reached by the suspension can be seen in Figure 5.

The maximum initial damping value of the suspension is about 200 Ns/m. If the initial value of dumping more than 200 Ns/m, then the design demand criteria would not sufficient. Therefore is needed the design planning which can give the initial damper value that smaller or equal to 200 Ns/m and the suspension design that can give a changeable damper value with the highest damper value can be achieved more than 6000 Ns/m (Table 1).

Table 1: Simulation Result.

W(m)	Car speed 20 km/jam (time to reach the value C) (dt)	The value of C be able to reach (Ns/m)
0.01	0.2	2000
0.02	0.3	2300
0.03	0.4	2700
0.04	0.5	2900
0.05	0.6	3200
0.06	0.65	3600
0.07	0.7	4000
0.08	0.75	4500
0.09	0.8	5000
0.1	1	6000

According to the Figure 5, it shows that the damping value which should be achieved by the suspension system is about 6000 Ns/m in a second, and then it can be able to return to the initial damping value in a second. To design the suspension model that suit to the criteria, it should have the initial damping value less than or equal to 200 Ns/m, and can reach the damping value more than 6000 Ns/m.

This suspension model has been reached the design criteria such as it has the initial damping value less than 200 Ns/m, and it has the highest damping value as shows in the Table 2.

The design of semi-active suspension system

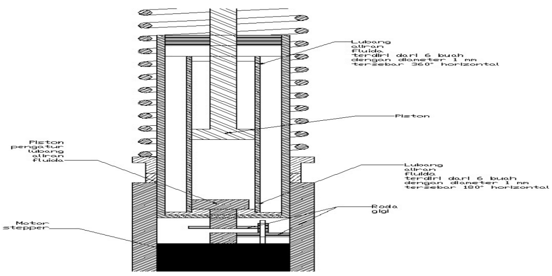

Figure 6: Design System Suspension Semi-Active.

The design of semi-active suspension system as Figure 6, it shows that the damping value can be controlled to reach the design criteria, i.e., it has the damping value less than 200 Ns/m and the highest damping value (c).

Conclusions

From the result of design and simulation of semi-active suspension model, so that it can be concluded as follows:

1. By using the state-space methods, the respond system (Respond oscillations) can be achieved less than a second and with the maximum overshoot of 5 %.
2. According to the design of semi-active suspension model, it can reach the changeable damping value from 100 Ns/m to higher than 100,000 Ns/m.
3. Within this semi-active suspension design, it can be able to control the damping value automatically so then the comfort can be achieved.

Table 2: The Characteristic of Semi-active Suspension Model.

Piston position Regulating of damper (°)	Damping value (Ns/m)
0	100
20	200
40	600
60	900
80	1500
100	5000
120	8000
140	10000
160	50000
180	100000

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