**IOSR Journal of Engineering (IOSRJEN)** **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 31-36

# Study and Analysis of Automobile Suspension System using Bond Graph Technique

Rahul Y. Girase[1],Dr. Animesh Chatterjee[2]
[1](Mechanical department VNIT Nagpur, South Ambazari road, Nagpur, India 440010)
[2](Mechanical department VNIT Nagpur, South Ambazari road, Nagpur, India 440010)

***Abstract:****In this paper Bond Graph based approach is used for the Design and Analysis of suspension system. The suspension model used for analysis is 'Two degree of freedom Quarter car model' and the controller use is PID Controller. The response of the system is simulated by using the software "Symbol's Shakti".Basically, the automobile suspension's design incorporates two criteria's which are road handling (Safety factor) and passenger comfort. In order to improve the ride comfort and stability by reducing the body acceleration in vehicles caused by the road irregularities, suspension system plays an imperative role in retaining the continuous road wheel contact for better road holding. In recent years, rapid developments have been observed in the field of automobile suspension because of advancing technology and electronic control systems. This paper work discusses the suspension control of a vehicle model using PID controller. The concept of using a Controlled suspension system for a vehicle is to provide the best performance of car control. Suspension system with controller offers more reliability than that of passive suspension systems. In this paper Bond Graph of Quarter car model is explained and compared the results with Controlled Suspension model of Quarter car system. PID controller is tuned using trial and error method with the help of Bond Graph Simulation module.*
***Keywords -****Quarter Car model, Bond Graph Modeling, PID Controller etc.*

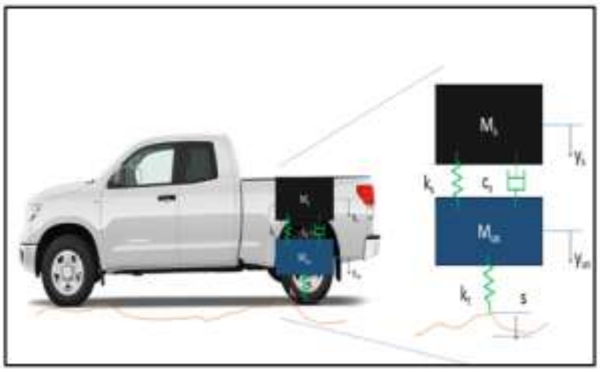
## I. Introduction

A Basic automobile suspension that is known as a passive suspension system consists of an energy storing element normally a spring and an energy dissipating element normally a shock absorber. The main weakness of the passive suspension is that it is unable to improve both ride comfort and road handling (safety factor) simultaneously. In the passive suspension system, as the stiffness and damping values are constant, there is always a trade-off between vehicle ride comfort and safety factor. That is, to improve the ride comfort we have to sacrifice safety factor and vice versa. One way to overcome such a problem, the car suspension system must be controlled. The introduction of the controller in the suspension system has better performance than passive suspension system for different road profiles. The controlled suspension system is consisting of sensors, controller, spring, damper,and actuator. The particular benefits of using a controlleris that the force of the system which is required to damp the car body oscillations can be changed with time to retain optimal performance and higher levels of optimization can be achieved due to the rapid time-variation achievable. In the present research work a quarter car suspension system is modeled using Bond graph method and compared the results with suspension model of Quarter car system with controller.

Bond Graph is a graphical representation of a physical dynamic system. It is similar to signal flow diagram or block diagram, the only difference is a representation is done with the help of bonds. In 1959, Prof. H. M. Paynter gave the revolutionary idea of portraying systems in terms of power bonds. In this method, elements of the physical system are connected through junction '1' or junction '0'. The bond graph is composed of the "bonds" which link together "single port", "double-port" and "multi-port" elements. In the automobile suspension system mass, spring and damper are represented as 'I', 'C' and 'R' elements in Bond Graph modeling. Bond graph is a very strong tool for analysis of systems where both Mechanical and electronics parts are used.It is rapidly emerging method to offer a new modeling and simulation methodology that is ideally suited to effectively unify knowledge pertaining to multi-domain systems for mechatronic applications.

## II. Quarter Car Suspension Model

It is simple two degree of freedom suspension system model mostly used for analysis purpose, since it can



| | |
|---|---|
| $M_s$ | mass of sprung car |
| $M_{us}$ | mass of unsprung car |
| $k_s$ | Suspension stiffness |
| $k_t$ | Tire stiffness |
| $c_s$ | Suspension damping coefficient |
| $y_s$ | Sprung mass displacement |
| $y_{us}$ | Unsprung mass displacement |
| s | Road input |

capture important characteristics of full model.

**Fig 2.1:** Passive quarter car suspension model

### 2.1 Mathematical Equations

$$M_s * \ddot{y}_s + c_s(\dot{y}_s - \dot{y}_{us}) + k_s(y_s - y_{us}) = 0 \quad (1)$$

$$M_{us} * \ddot{y}_{us} + c_s(\dot{y}_{us} - \dot{y}_s) + k_s(y_{us} - y_s) + k_t(y_{us} - s) = 0 \quad (2)$$

$$\begin{bmatrix} M_s & 0 \\ 0 & M_{us} \end{bmatrix} \begin{bmatrix} \ddot{y}_s \\ \ddot{y}_{us} \end{bmatrix} + \begin{bmatrix} c_s & -c_s \\ -c_s & c_s \end{bmatrix} \begin{bmatrix} \dot{y}_s \\ \dot{y}_{us} \end{bmatrix} + \begin{bmatrix} k_s & -k_s \\ -k_s & k_s + k_t \end{bmatrix} \begin{bmatrix} y_s \\ y_{us} \end{bmatrix} = \begin{bmatrix} 0 \\ k_t s \end{bmatrix} \quad (3)$$

That is, $M\ddot{y} + C\dot{y} + Ky = F$

### 2.2 Bond Graph Model

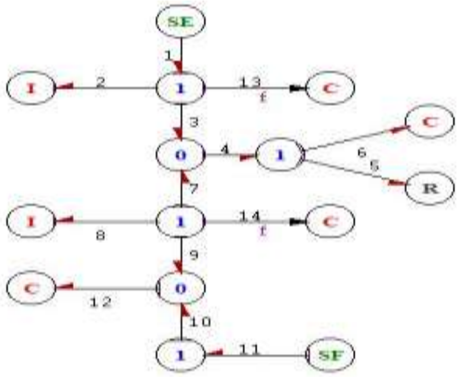



**Fig 2.2:** Bond graph model of passive quarter car suspension

### 2.3 Representation of Suspension Parameters in Bond Graph

Road input is represented by 'SF' element (Source of flow) and road profile is considered by a single bump, and SF is given as, $SF = h * w * cos(w * t)$

Gravitational force is represented by 'SE' element (Source of effort) and SE $= M_s * g$;

Sprung mass = 'I' element connected by bond number 2

Unsprung mass = 'I' element connected by bond number 8

Suspended spring= 'C' element connected by bond number 6

Unsprung (Wheel) spring= 'C' element connected by bond number 12

Damper = 'R' element connected by bond number 5

## III. Car Suspension Model With Pid Controller

As passive suspension system can't provide variable damping force for variable road excitations, it is necessary to introducea controller in the suspension system so that we can vary damping force according to different road profiles as well as different velocities. By controlling damping force we can maintain the balance between Passenger comfort and Road handling (safety). Because of their simplicity and wide acceptability Proportional Integral and Derivative (PID) controllers are playing an imperative role in controlling car oscillations.

PID controllerhas the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability.

Three different forces are applied on the mass to bring it to the required position

i. Force proportional to the error in position
ii. Force proportional to the integral of error in position

iii. Force proportional to the rate of change of position

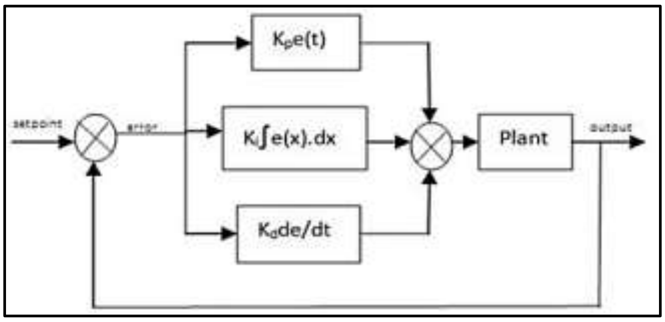



**Fig 3.1:** Block diagram of PID controller

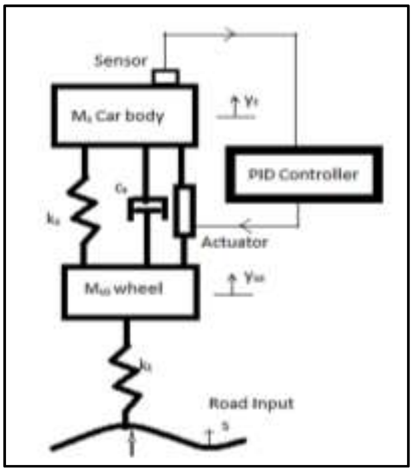



**Fig 3.2:** Block diagram of car suspension with PID controller

### 3.1 Mathematical Equations

$M_s * \ddot{y}_s + c_s(\dot{y}_s - \dot{y}_{us}) + k_s(y_s - y_{us}) - f_a = 0$ (4)

where $f_a$ is actuator force

$M_{us} * \ddot{y}_{us} + c_s(\dot{y}_{us} - \dot{y}_s) + k_s(y_{us} - y_s) + k_t(y_{us} - s) + f_a = 0$ (5)

$$\begin{bmatrix} M_s & 0 \\ 0 & M_{us} \end{bmatrix}\begin{bmatrix} \ddot{y}_s \\ \ddot{y}_{us} \end{bmatrix} + \begin{bmatrix} c_s & -c_s \\ -c_s & c_s \end{bmatrix}\begin{bmatrix} \dot{y}_s \\ \dot{y}_{us} \end{bmatrix} + \begin{bmatrix} k_s & -k_s \\ -k_s & k_s + k_t \end{bmatrix}\begin{bmatrix} y_s \\ y_{us} \end{bmatrix} = \begin{bmatrix} f_a \\ k_t s - f_a \end{bmatrix} \quad (6)$$

That is, $M\ddot{y} + C\dot{y} + Ky = F$

### 3.2 Bond Graph Modeling:

3.2.1 PID Controller:

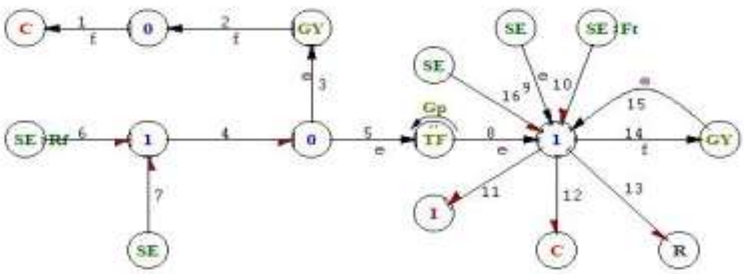


**Fig 3.3** Bond graph model of PID controller

3.2.2 Car suspension model with PID Controller:

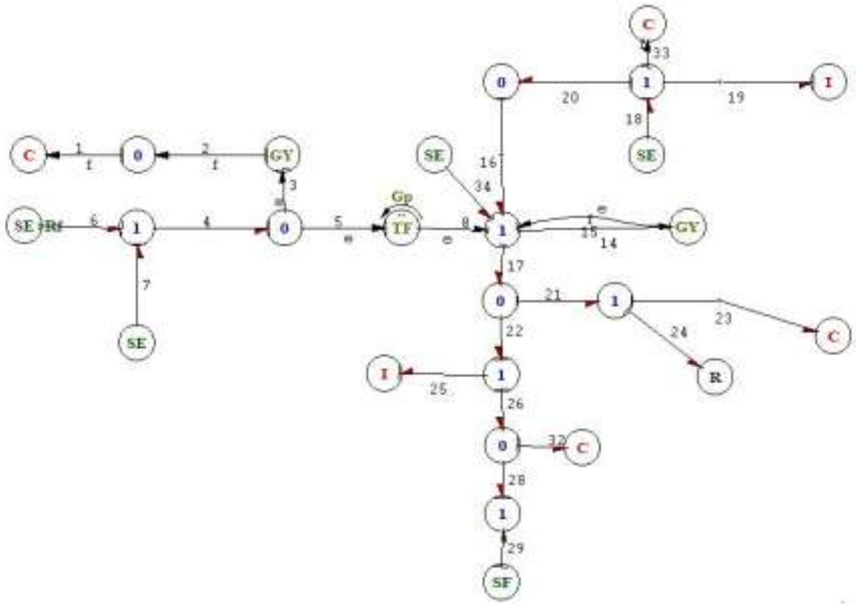


**Fig 3.4:** Bond graph model of car suspension with PID controller

## IV. Simulation And Result

**Table 1.** Simulation parameters[1]

| S. No. | Parameter | Symbols | Value | Unit |
|---|---|---|---|---|
| 1. | Sprung mass | $M_s$ | 240 | kg |
| 2. | Unsprung mass | $M_{us}$ | 36 | kg |
| 3. | Stiffness of spring | $k_s$ | 16000 | N/m |
| 4. | Stiffness of wheel | $k_t$ | 160000 | N/m |
| 5. | Damping coefficient | $c_s$ | 980 | Ns/m |
| 6. | Height of bump | h | 0.1 | m |
| 7. | Speed of car | v | 20 | m/s |
| 8. | Width of bump | w | 0.15 | m |

### 3.2 Simulation of Quarter Car suspension model:

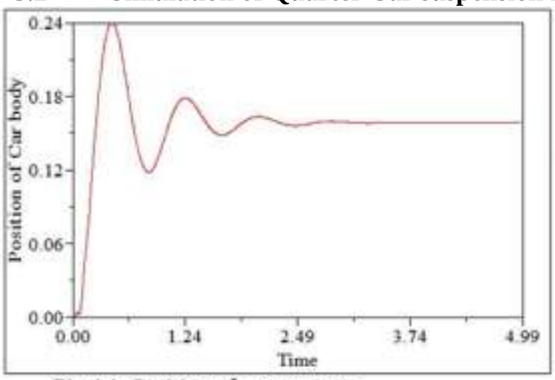



**Fig 4.1:** Position of sprung mass

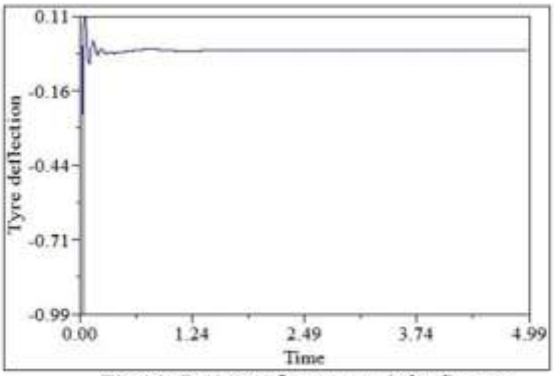



**Fig 4.2:** Position of unsprung (wheel) mass

### 4.2 Simulation of Car suspension system With PID Controller:

**Table 2.** PID Controller parameters

| S. No | Parameter | Symbol | Value |
|---|---|---|---|
| 1. | Proportional Gain | Kp | 8500 |
| 2. | Integral Gain | Ki | 5500 |
| 3. | Derivative Gain | Kd | 1800 |

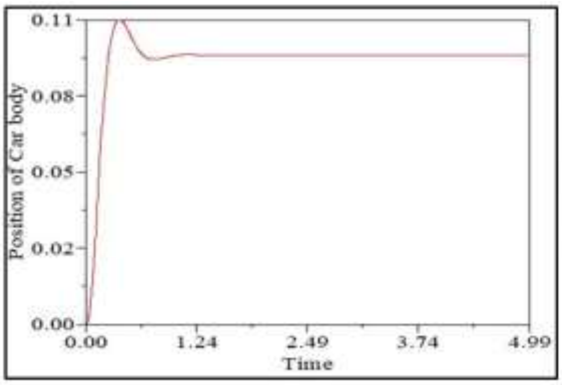



**Fig 4.3:** Position of sprung mass

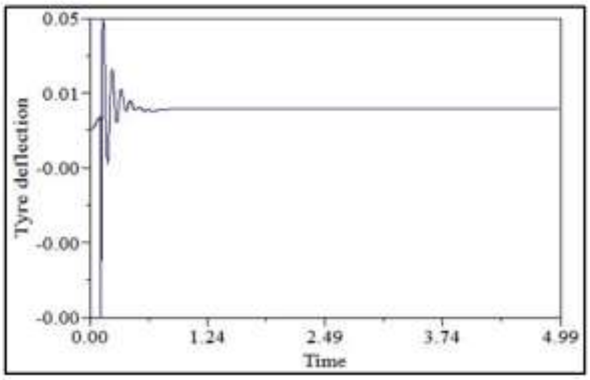



**Fig 4.4:** Position of unsprung (wheel) mass

## V. Result

Analysis results of suspension system for quarter car model for speed bump of 0.1 m shows that sprung mass (Fig.4) has peak amplitude of 0.24 m with percentage overshoot of 48% and settling time of 2.69 seconds. These values are very high and undesirable from comfort point of view. High overshoot is not desirable for better working of suspension and for its long life. The result of unsprung mass displacement(Fig.4.1)also has peak amplitude of 0.11 m which is also undesirable in driver's point of view and ride quality. These problems with passive suspension are overcome by introducing controller in the suspension system. With the use of controller peak amplitude of sprung mass (Fig.4.2) is reduced to 0.11 m with the percentage overshoot of 10% which is desirable. The response of car suspension without and with the use of controller (Fig.4.4) is compared and from that it is clear that, with the use of PID controller, it is possible to decrease the percentage overshoot, steady state error, rise time and settling time (Table 3).Hence, performance of suspension system is improved.

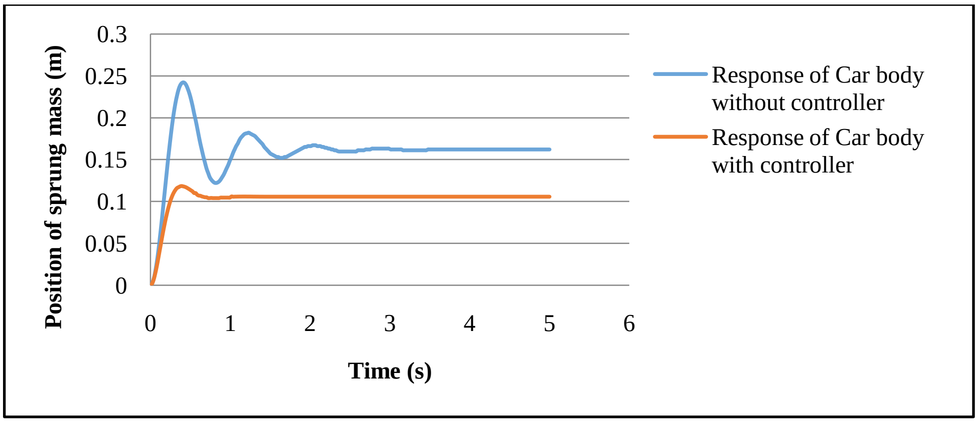



**Fig 4.5:** Comparison between position of sprung mass of suspension system with and without controller

**Table 3.** Comparison of the results

| | Peak amplitude (m) | Overshoot (%) | Steady state error | Rise time (s) | Settling time (s) |
|---|---|---|---|---|---|
| **Without Controller** | 0.24 | 48 % | 0.06 | 0.257 | 2.69 |
| **With Controller** | 0.11 | 10 % | 0 | 0.22 | 0.95 |

## VI. Conclusion

In this paper, the response of car suspension system is simulated in bond graph software 'SYMBOLS SHAKTI'. The methodology was developed to design an automobile suspension for a passenger car by designing a controller, which improves performance of the system with respect to desired goals compared to passive suspension system. I have found optimal parameters of PID controller by manual tuning method (trial and error method) and compare the performance of car suspension system with and without controller using Bond Graph Simulator. The controlled suspension system is achieved steady state response faster than other passive systems.

The objectives of this project have been achieved.That is, with the use of PID controller, the performance of suspension system is increased for different road inputs and for different velocity inputs.

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