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Simulation Study of Active Quarter Car Model Using MatlabAnd Simulink Software

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Abstract

This paper is to Improvement the Passenger Ride comfort,Vehicle stability, safety, Road Holding in an active Quarter car model. The main objective is to obtain a stable, robust, and controlled PID system. It is necessary to use the PID controller to increase the stability and performance of the System.The controller selection and design aimed to achieve good passenger ride comfort and health, stability, and passenger body acceleration and displacement Response under Uneven road excitations. The performance of the designed controlleris evaluated using simulation work in the time and frequency domain. Simulation results show that the proposed PID control scheme can successfully achieve the desired ride comfort and passenger safety compared to passive and PID controlled cases in an active quarter car model.Ride comfort is anImportant key issue in the design and Manufacture of modern automobiles. This paper addresses the ride comfort analysis of the quarter car model active suspension system. The active suspension system is proposed based on the Proportional Integral Derivative (PID) control technique to enhance its ride comfort. The ride comfort analysis of the System has been determined by computer simulation using MATLAB/Simulink.

Keywords- *Active Suspension, PID controller, Passenger body, Quarter car model, Ride comfort...*

I. INTRODUCTION

Suspension System Performs multiple vehicle body tasks related to control of generated vibrations from Rough Road to Provide good passenger ride comfort, Road holding capability by keeping continuous wheel contact with varying road surface profiles.

A car suspension system is a mechanism that Physically separates the Vehicle body from the Vehicle wheels.The suspension system isanimportantpart of the vehicle. Therefore, it is quite necessary to design a finersuspension system to improve vehicles' quality. Since the Road disturbances may includeUncomfortable Shake and Noise in the vehicle body, it is important to study its vibrations.TheSuspension consists of the System of springs, Damper,and linkages that connects a vehicle to its wheels.The Parameters of Passive Suspension system are generally fixed, being chosen to achieve a certain level of compromise between Road Holding, load carrying, and comfort.

The vehicle suspension system's main function is to Minimize the vertical acceleration transmitted to the passenger, which directly provides road comfort. There are mainly three types of suspension systems: passive, semi-active, and active suspension systems.

Passive Suspensionisconsists: Springs and Dampers, then If theActiveSuspensionis Externally controlled.There are many situations in which assuming linearbehavior for Suspension System Might Provide satisfactory Results. Ontheother hand, some Circumstances or Phenomena require a nonlinear solution. A nonlinear structural behavior may arise because of geometricand material nonlinearities and change in the boundary conditions and structural integrity.There will be a difference in the amplitude of the mainmass obtained by theoretical and Analytical Methods.Ride comfort is a key issue in the design and Manufacture of modern automobiles. The design of Advancedsuspensionsystems is one of the requirements, which provide a comfortable Ride by Absorbing the road disturbances and maintaining vehicle stability. A Good Amount of Research Activities has been directed to improve Ridecomfort, especially over the last decade.The suspension system performs multiple tasks in the vehicle body related to control of generated vibrations from road irregularities to provide good passenger ride comfort and road holding capability by keeping continuous wheel contact with varying road surface profiles.

II. Passive suspension system

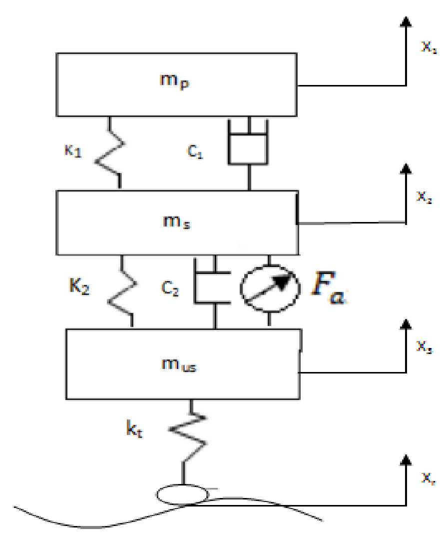
Passive Suspension Systemisan uncontrolled type and works on the combination of spring and damper system having fixed stiffness and damping characteristics. Such a passive System provides limited suspension performance in a certain Frequency Range. To achieve the desired conflicting tasks in vehicles, Automotive Manufacturers have developed semi-active and active suspension system based technology. Generally, a semi-

active suspension is assembled with magnetorheological or electro-rheological dampers, generating variable damping force in the vehicle's suspension system. The passive suspension system is an open-loop control system. It only designs to achieve certain conditions. Any mechanical part cannot adjust the characteristic of passive suspension fix and. The problem of passive Suspension is if it designs heavily damped or too hard Suspension, it will transfer a lot of road input or throw the car on the Road's unevenness. Then, if it is lightly damped or soft, it will reduce the stability of the vehicle in turns or Change lane or swing the car. Therefore, the Performance of passive Suspension depends on the road profile.Various control approaches based on the PID controller have been proposed to achieve desired Ride comfort and vehicle handling issues. The vibration suppression results of sprung mass, unsprung mass, and suspension systems vary based on various developed and implemented control strategies.
They are related to the passenger ride comfort and vehicle handling issues compared to passive one through simulation results. A quarter car modelwith seat suspension and main Suspension has been successfully used to study the passengers' ride comfort and vehicle response against the uneven road surface-induced vibrations. Passenger Seat suspension plays a vital role in controlling passenger seat vibrations in-vehicle systems during driving conditions, thus improving the health and safety of traveling passengers. A quarter car model is the simplest car model compared to half car and full car model and provides the vehicle performance results taking only vertical motion into account. In contrast, vehicle roll and pitch motions are ignored. The active quarter car model is an advanced stage of the traditional passive quarter car model obtained by integrating additional controllers.

A vehicle suspension is a Nonlinear system that poses significant challenges to the designer. Its main purpose is to ensure the Safe, Handling, and controlled movement of the car. This requires different responses depending on the characteristics of the road surface encountered. It must also cushion the driver from the more severe shocks while transmitting enough information to give confidence that the vehicle will perform as expected to driver inputs.
Car is divided into three categories: Full car model, half-car-model, and Quarter car model. To study the behavioralResponse when under the motion to various road irregularities, the entire vehicle for study becomes difficult and tedious. Quarter-car models are extensively used in automotive engineering due to their simplicity and provide qualitatively correct information, at least in the initial design stages of vehicle dynamics.

III. Active Suspension System

An active suspension system is highly successful in achieving the desired tasks compared to passive and semi-active one. The active Quarter suspension system can suppress the passenger seat, sprung mass and un-sprung mass vibrations, and minimize suspension deflection effectively in a wider frequency range. Active suspension system assembly contains various Mechatronics based devices such as actuators and sensors in combination with spring and Damper. The assembled sensors receive the signals from the vibrating suspension structure. These signals are transferred to the assembled controllers, which supply the Required amount of damping force using Controllable Actuators in the suspension system. Therefore, active suspension systems are the top choice for automotive developers and researchers due to attractive characteristics of Providing high Ride comfort during accelerating and braking conditions and the best Road holding ability during the running period.
An Active Suspension System has the Ability to Store, Dissipate,and introduce Energy to the System. This objective can be achieved by Minimizing the Passenger Seat and Vertical Car Body Acceleration. Excessive wheel travel will result in a Non-optimum attitude of the tire relative to the Road that will Cause Poor Handling and Adhesion.

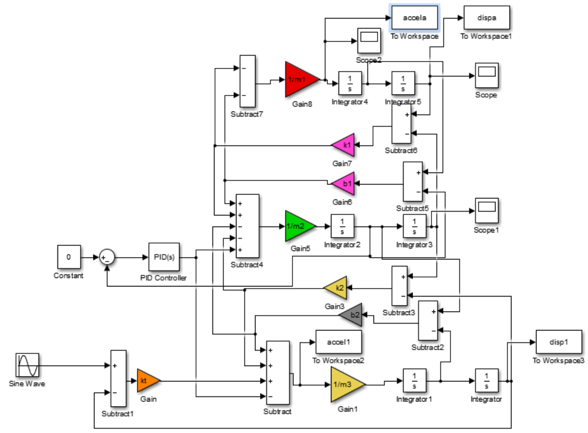


(FIG.1: Active Quarter Car Suspension System)

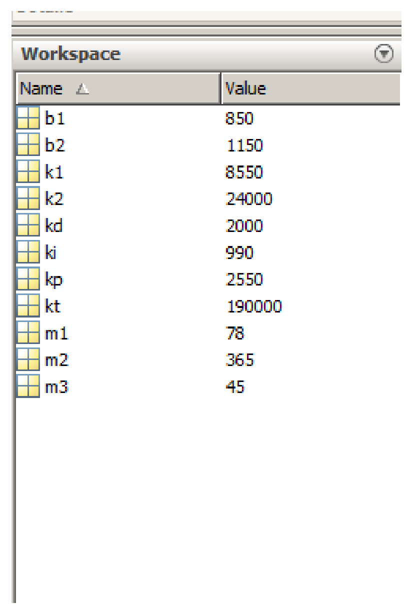
The mathematical equations of the active quarter car model with three-degrees-of-freedom as follows:

$m_p\ddot{X}_1$ + C$_1$($\dot{X}_1$-$\dot{X}_2$)+K$_1$ (X$_1$-X$_2$)=0
$m_s\ddot{X}_2$ - C$_1$($\dot{X}_1$-$\dot{X}_2$) –K$_1$ (X$_1$-X$_2$) + C$_2$ ($\dot{X}_2 - \dot{X}_3$) +k$_2$ (X$_2$-X$_3$) +F$_a$ + $\bar{d}$ =0
m$_{us}\ddot{X}_3$ -C$_2$ ($\dot{X}_2 - \dot{X}_3$)- k$_2$ (X$_2$-X$_3$)- F$_a$ - $\bar{d}$=0

The Active Quarter Car Model having three degrees of freedom with a controlled primary Suspension system, is shown in Figure1. It is used to study the passenger seat vibrations, sprung mass vibrations, suspension response to road input, and control Effort Requiredfor vibration control. The Mass Parameters of this quarter car model are passenger seat mass: sprung mass, *ms,* and un-sprung mass, *mus* respectively. The damping and stiffness parameters for the main Suspension are c_2 and k_2 while for the passenger seat suspension, the damping and stiffness parameters arerepresented by c_1 and k_1 respectively. The Tyre stiffness is represented by k_t.The damping force supplied bytheactuator in the main suspension system isdenotedbyFa. The displacement of the passenger seat sprung mass, unsprung mass, and road profile are X$_1$, X$_2$, X3, and Xr, respectively, while $\bar{d}$ indicates bounded external disturbance.
Active Suspension is a Type of Automotive Suspension that Controls the Vertical Movement of the Wheels Relative to the Chassis or Vehicle Body with an onBoard System. It has the Ability to Store, Dissipates, and introduce Energy to the System. Fully Active Suspension Systems use Electronic Monitoring of Vehicle conditions, Coupled with the means to impact vehicle suspension and behavior in Real-Time to control the car's motion Directly. They use Separate Actuators, which can exert an independent force on the Suspension to improve the riding characteristics. In another way, active Suspension can give Suspension better performance by having force actuator, a closed-loop control system. The Force Actuator is a mechanical part that is added inside the System that control by the controller. The controller will calculate Either Add or Dissipate Energy from the System, from sensors' help as an input. Sensors will give the data of the road profile to the controller. Therefore, an active suspension system shown in Figure1 is needed where there is an Active element inside the System to give both conditions to improve the performance of the Suspension system.



(FIG.2: Simulink Model of Quarter car)



Workspace

Name	Value
b1	850
b2	1150
k1	8550
k2	24000
kd	2000
ki	990
kp	2550
kt	190000
m1	78
m2	365
m3	45

Matlab Simulink method:InMatLab is Software in which Simulink is a part of the Analyzing of Designs. Simulink design method Simulink software models, Simulates, and analyses dynamic systems. When we model the System and see what happens with Simulink, We can easily build models from scratch or modify existing models to meet our needs. Simulink turns ourComputer into a laboratory for Modeling and Analyzing systems.

A.PID CONTROLLER

Proportional–Integral–Derivative (PID) Controller has widely used in Mechatronics based industries due to its Design Simplicity and effectiveness. A PID controller is also known as a Three-term Controller and follows the input Reference signal. It Combines Proportional, Integral, and Derivative of the Difference in Reference signal position and Current Position of the signal supplied From the Controlled System.

The output signal, $UPID$ (t) Generated by the PID controller is based on the following Law:
Where (t) is the error signal defined as $(t) = yref - y$, while $yref$ is the reference position, and y is the current position whereas, KI and KDareProportional, Integral and Derivative gains respectively.The control signal u (t) is the sum of three terms. Each of theseterms is a function of the tracking error e (t). The term Kpindicates that this term isproportional to the error. The termKi/s is an
integral term, andthetermKdsis derivative. Each of the terms works "independently"of the other.
The PID sliding surface expressed in the following equation :
wherekp, ki, and k_d are the PID Parameters. For a Third-order system, The slidingsurface can be defined as in :

$$S(t) = k_p\dot{e}(t) + k_i\int_0^t e(\tau)\ d\boldsymbol{\rho} + k_d\dot{e}(t)$$

The tracking error can be determined as a differencebetween the trajectory and the actuator's actual position. Since the linear model is a third-order model, the thirdderivative of the error is:

$$e(t) = x_r(t) - x_p(t)$$

IV. Simulation Results and Discussion

To study the ride comfort issues in Graphical and Mathematical results, simulation models for active and passive quarter car systems were designed. The random road profile used in simulation work is shown in Figure 2. The quarter car model speed was set as 40 km/hr while the simulation was run for 4 seconds.

TABLE 1: VALUE OF VARIATION OF MASS

		ACCERETION		DISPLACEMENT	
		MAX. VALUE	RMS VAUE	MAX. VALUE	RMS VALUE
PASSIVE	285	0.8429	0.561771	0.00601	0.001856
ACTIVE		0.8075	0.538875	0.004208	0.001472
PASSIVE	325	0.842947	0.561771	0.00601	0.001856
ACTIVE		0.639788	0.42468	0.003383	0.001165
PASSIVE	365	0.842947	0.561771	0.00601	0.001856
ACTIVE		0.523791	0.350213	0.002822	0.000965

TABLE 2: VARIATION OF DAMPING

			ACCELERATION		DISPLACEMENT	
			MAX.	RMS	MAX.	RMS
PASSIVE	MIN. VALUE	900	0.7540	0.4902	0.0058	0.0018
ACTIVE			0.5300	0.3571	0.0032	0.0010
PASSIVE	NOMINAL VALUE	1150	0.8084	0.5350	0.0058	0.0018
ACTIVE			0.5784	0.3903	0.0033	0.0011
PASSIVE	MAX. VALUE	1400	0.8730	0.5878	0.0059	0.0019
ACTIVE			0.6435	0.4279	0.0034	0.0012

TABLE.3: VARIATION OF STIFFNESS

			ACCELERATION		DISPLACEMENT	
			MAX.	RMS	MAX.	RMS
PASSIVE	MIN. VALUE	20500	0.8121	0.5485	0.0055	0.0017
ACTIVE			0.5959	0.3988	0.0031	0.0011
PASSIVE	NOMINAL VALUE	24000	0.8730	0.5878	0.0059	0.0019
ACTIVE			0.6921	0.4658	0.0037	0.0013
PASSIVE	MAX. VALUE	27500	0.9656	0.6292	0.0063	0.0020
ACTIVE			0.6541	0.4373	0.0035	0.0012

The Active and Passive Quarter Car Models Performance was Evaluated in Vibration Control of Passenger Seat, Sprung Mass, and Suspension Systems, Respectively. The Selected Mathematical values of Quarter car model for simulation work are as follows: Passenger seat Mass, mp = 78 kg; sprung mass, ms = 365 kg and un-sprung mass, mus = 45 ; the Damping and stiffness Parameters of Main and Passenger Seat Suspension are c1 = 850 Ns/m , c2 = 1150 Ns/m, k1 = 8550 N/m, k2 = 24000 N/m respectively. The TyreStiffness kt is having a value of 190,000N/m.Kp =2550;ki=990;kd=2000.

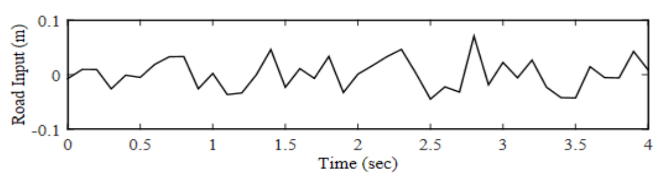


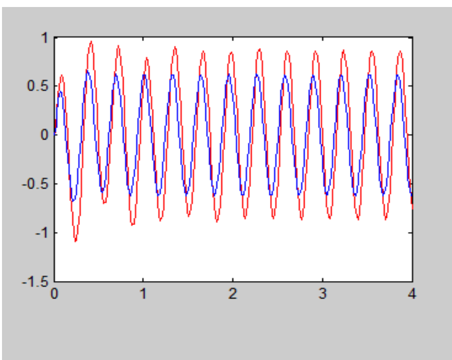
Table 4: Variation of Quarter Car Parameters

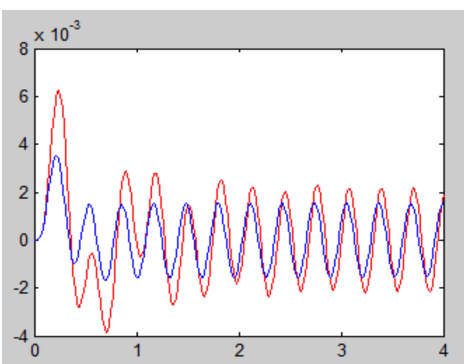
Parameter Nominal Value Variation
m_s325 kg± 40 kg
$c_2$1400 N/m/s± 350 N/m/s
$k_2$24000 N/m ± 3500 N/m

The Results Obtained after the Simulations in the time domain are Presented Graphically. The figure shows the Response of the Passenger seat, sprung mass, and suspension stroke. Thefigure shows the damping force supplied and the PID controller's power in the main suspension system. It can be seen from the figure that passenger seat and sprung mass vibrations are suppressed very much by an active suspension system compared to a passive one in terms of acceleration and displacement criterion. The displacement movement of passenger seat suspension andmainSuspension is also lower for Active Suspension System than Passive one as Seen in Figure.

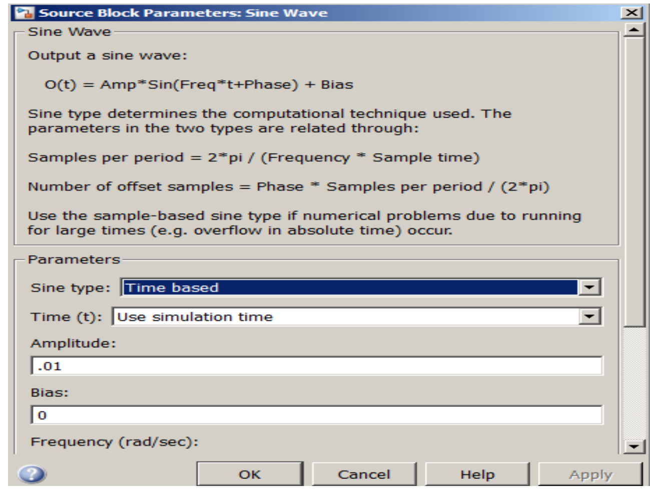
Active Quarter car

Passive Quarter car

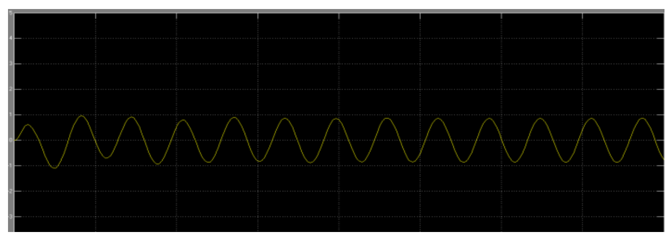




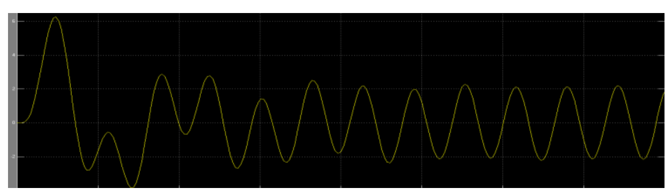
(FIG.3: Passenger Seat Response (a) Acceleration (b) Displacement)



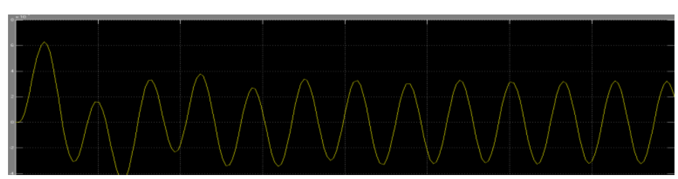
Given the input parameters From Road Unevenness that we Run the program and the graphical representation of the System of equations, Then calculate the Passenger mass, Sprung Mass, and Un-sprung Mass movements of the vehicle and its Suspension. In Fig. is presented Passenger Mass displacement, PassengerMass AccelerationDeflection.Non-uniform Road Profile functions are used to examine the performance of the System.



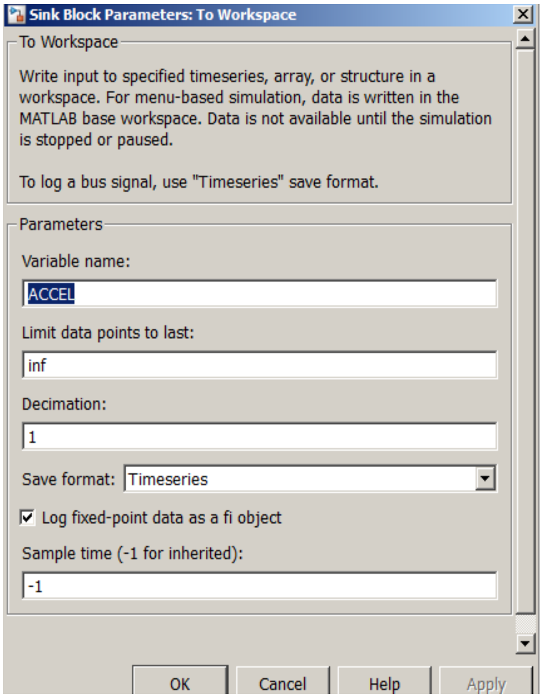
(FIG.4: Passenger Mass Acceleration Deflection)



(Fig.5: Passenger seat Displacement Deflection)



(FIG.6: Sprung mass Displacement Deflection)



V. PSD (POWER SPECTRAL DENSITY)

PSD Signals for Active Suspension System with STSMC controller are Much Suppressed inMagnitude Compared to Passive one, thus Showing the Superior Performance of STSMC controlled Active quarter car model in terms of Road induced Vibration control.Vibrationstransmitted from Road Surfaces to Vehicle Structures also affect the bodyparts of traveling passengers. The Power Spectral Density (PSD) Representation of Road Profilescan be used to assess the Road Roughness and as an input to vehicledynamics. A power spectral density (PSD)Analysis of a Road profile, However, Can give moreDetailed information about the Pavement Surface,including roughness information for specificLongitudinal wavelengths. The PSD is often Approximated with a Simple function, usingonly a Few Parameters. The More or less General Availability of High-Speed Profile-Meters has Givendramatically increased possibilities to Analyse imperfections in road profiles andsurfaces. The most common reason for collecting Longitudinal Road ProfileData (called just road profiles in the following) is to form a basis for the Analysis ofroad Evenness that a rational Pavement Management Requires. To make such ananalysispossible, the Very Large Amount of Data Made Available by Modern AssessmentTechniques Must be Reduced to Manageable and More informative dimensions. Thisis normally done by the continuous computation of some kind of evenness index.InSweden, the index normally used is the International Roughness Index (IRI). TheIRI is adequately related to the comfort experienced in a private car but does not allowmuch room for analysis of road surface dependent effects experienced by the roaduser. Such vibration exposure with high intensity and longduration can lead to health risk, injury to body parts, and discomfort to sittingoccupants in a running vehicle. Hence, whole-body vibration measurement is performedusing ISO 2631-1.

VI. CONCLUSIONS

This paper presented the PID controller's successful application in the activesuspension system of the quarter car model in vibration control of passenger seat, sprungmass, and suspension system under random road excitation. Simulation results in the time andfrequency domain showed the proposed STSMC controller's effectiveness in providinghigh ride comfort to traveling passengers compared to a passive one. The main objective is to obtain a Stable, Robust, and Controlled System by tuning the PID Controller. It is necessary to use the PID controller to increase the stability Andperformance of the System. The ProposedController also showed the Robust behavior when Magnitudes of three parameters,namelysprung mass, damper damping, and spring stiffness, were varied.The methodology was developed to design an active suspension for a passenger car by Designing a controller, which improves the performance of the System with respect to Design Goals Compared to a Passive suspension system. Mathematical modeling has been performed using a Three degree-of-freedom model of the quarter car model for passive and active suspension systems considering only bounce motion to Evaluate the Performance of Suspension concerning various contradicting design goals. The PID controller design approach has been examined for the Active System. Suspension travel inactive case has been found Reduced. By including an active element in the Suspension, it is Possible to Reach a better compromise than is possible using purely Passive Elements. The potential for improved ride comfort, Vehicle Stability, and better Road handling using PID controller design is examined.

VII. SCOPE OF FUTURE WORK

Future work must focus on other types of controllers. In addition, the Mathematical model using MATLAB & SIMULINK SOFTWARE can Further improved and validated using Experimental Results. Additional efforts to improve the mathematical model of suspension systems include more half-car or full car Models.

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