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Optimization of Passive Quarter Car Suspension System for Ride Comfort

***Soniya Paimode*[a,]**Prof. B. M. Randhwan*[b]**

[a]*PG Student, Department of Mechanical Engineering, SVCoET, Rajuri, Punr, India.*
[b]*Guide and HoD, Department of Mechanical Engineering, SVCoET, Rajuri, Punr, India.*

ABSTRACT

The main functions of an automotive suspension system are to provide vehicle support, stability and directional control during handling maneuvers and to provide effective isolation from road disturbance. These different tasks result in conflicting design requirements. Directional control and stability requires a suspension that is neither very stiff nor very soft. Insensitivity to external loads requires a stiff suspension, whereas good ride comfort demands a soft suspension. In a conventional passive suspension system, the designer is faced with the problem of choosing the suspension stiffness and damping parameters, which inevitably involves a difficult compromise in view of the wide range of conditions over which a vehicle operates. In this paper, a quarter car suspension system is modelled and simulated in Matlab/Simulink environment. The suspension system is then optimized using Jaya algorithm for ride comfort and road holding. Using Matlab we find the optimized solution for the spring stiffness. The spring is then manufactured and the spring is then tested along with strut on quarter car test rig. It is observed that the simulation and experimental results are in close agreement. Also optimized strut has less RMS sprung mass acceleration as compared to un-optimized strut. Around 19% reduction in RMS sprung mass acceleration is observed for optimized strut thus improving the ride comfort.

Keywords: Optimization, Quarter Car, Test Rig, Jaya Algorithm

1. Introduction

The main functions of an automotive suspension system are to provide vehicle support, stability and directional control during handling maneuvers and to provide effective isolation from road disturbance. These different tasks result in conflicting design requirements. Directional control and stability requires a suspension that is neither very stiff nor very soft. Insensitivity to external loads requires a stiff suspension, whereas good ride comfort demands a soft suspension.

The conventional system i.e. passive suspension system, which comes *as is*, is a system of springs, shock absorbers, bushings, rods, linkages and arms. Vehicles generally have two suspension systems – one for the front wheel and other for rear. These two systems work together to control driving and breaking forces to provide smooth ride for driver and passengers.

Nomenclature

m Mass (kg)	c Damping (N/ms)	k Stiffness (N/m)

Subscript s Sprung , us Unsprung

1.1. Suspension System

The vibration generated in vehicle produce mechanical damage, physiological response and subjective responses to humans. Human

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* *Corresponding author..*
E-mail address: paimodesoniya@gmail.com

engineering dealt with various effect of vibration on the different parts of human body. The vehicle vibration produces physiological effect on humans. The evidence suggest that short time exposure to vibration cause small physiological effect such as increase in heart rate, increase in muscle tension long term time exposure to vibration causes effect such as disc and spine & effect on digestive system peripheral veins & the femalereproductive organ.

When spring supported mass such as that of a motor vehicle chassis is given an impulse, it is set in vibratory motion & it keeps on vibrating until the energy of impulse completely died out in overcoming damping forces. There are different source of vehicle vibration i.e. road roughness, the unbalance of engine whirling of shafts the cam forces & tortional fluctuations. Depending upon the cause of vibration may be free or forced. The free vibration may occur when the vehicle passes over isolated irregularity in the road surface, which may die off as a result of dissipation of energy in damping. Then the forced vibration may result when disturbances occur persistently such as passing over obstacles on the proving road. In this case even if there is damping, the vibration may persists & built up an undesirable level.

Ghuman Kuljit Singh: After going through the research reported by various researchers in the field of whole-body vibration and its effect on human being, It has been concluded that musculoskeletal injuries of the hip, buttock, neck, high and low back pain are associated with the operators of on-road and off-road vehicles (or other related equipment). These musculoskeletal disorders are developed in human body due to exposure to whole-body vibration and awkward postures during operations.

Shivakumara BS & Sridhar V : Vibration is a physical disturbance that occurs in machines and automobiles. The nature of vibration that is present in a vehicle depends upon the dynamic characteristics of the automobile and road surface characters. Its effect on the human body depends mainly on the frequency, magnitude, direction, area of contact and duration of exposure. Exposure to HAV and WBV will result in transmission of vibratory energy to the entire body and leads to localized effects. It affects comfort, normal functioning of the body and health. Exposure to certain frequencies of vibration may have effects on specific systems of the body depending upon the natural frequencies of it and acceleration of the vibration at that frequency. The acceleration depending upon its magnitude and duration of exposure leads to unhealthiness of the human being. The HAV and WBV accelerations measured on different roads on different motorcycles shows it is dangerous even considering short duration of riding. The vibration effects are more hazardous on motorcyclist. As for as possible, measures is to be taken to avoid prolonged exposure to vibration.

In order to analyze the behavior of a dynamic system one needs a mathematical model of the system which represents the kinematic and dynamic behavior of the system in equation.

Researchers have utilized quarter car models to compare the essential performance criteria of an active system with well-designed passive system. This model consists of a sprung mass and unsprung mass supported by springs and dampers. Christophe Lauwerys and et. al and T. Yoshimura and et. al. presented the design of a robust linear controller for an active suspension mounted in a quarter car test-rig, which does not require a physical model of eitherthe car or the shock-absorber. Chuanyin Tang, TiaoxiaZhang and Nukran Yagiz and et. al.

1.2. Optimization of Quarter Car Suspension System

R.V. Rao discuss in Jaya: A simple and new optimization algorithm for solving constrained andunconstrained optimization problems concluded that the results have shown the satisfactory performance of Jaya algorithm for the considered unconstrained optimizationproblems. It may be concluded that the proposed Jaya algorithm can be used for solving the constrained as well as unconstrained optimization algorithms.[21]

R.Venkata Rao & G.G. Waghmare discuss a new optimization algorithm for solving complex constrained design optimization problems concluded that compared to other advanced optimization methods, the Jaya algorithm does not require selection of algorithm-specific parameters and this feature makes to real life optimization problems, easily and effectively. [23]

R. Venkata Rao studied a simple and new optimization algorithm for solving constrained and unconstrained optimization problems and concluded thatsatisfactory performance of Jaya algorithm for the considered unconstrained optimization problems. It may be concluded that the proposed Jaya algorithm can be used for solving the constrained as well as unconstrainedoptimization algorithms. [24]

Salim haidar and Ali mohammadzadeh studied the analysis and design of vehicle suspension system using matlab and Simulink and concluded that these software tools in vibrations greatly improve students' ability to face challenging application problems, find an appropriate solution successfully, and gain a strong sense critical thinking that helps them unite knowledge with human experience. Matlab and Simulink are to expose vibration with industrial implication. [25]

This paper presents mathematical modeling of linear quarter car model. Optimization of quarter car suspension system is carried out JAYA algorithm in Matlab environment. The optimized parameters are then further tested on test rig.

2. System Modeling

2.1. Quarter Car Model

A linear 2-DOF system is used as a model for the road vehicle. The two masses m_{us} and ms, of the vehicle model represent the wheel (and axle if there is any) and the vehicle body (often called the unsprung and the sprung mass, respectively). These masses (representing one half or aquarter of a real car). The spring stiffness are ks, k_t and the damper stiffness is cs.

To analyze the effectiveness of a two degree-of-freedom isolation system we consider the base supporting the two degree-of-freedom system to be a moving base as shown in Fig.1. In analyses of such systems, one usually assumes that the masses are initially at rest and that there are no applied forces directly on the inertial elements and $x_r(t)$ is given. Eqs. to account for the moving base become,

$$m_s\ddot{x_s} = k_s(x_{us} - x_s) + c_s(\dot{x_{us}} - \dot{x_s})$$

$$m_{us}\ddot{x_{us}} = -k_s(x_{us} - x_s) - c_s(\dot{x_{us}} - \dot{x_s}) - k_t(x_{us} - x_r) \qquad (1)$$

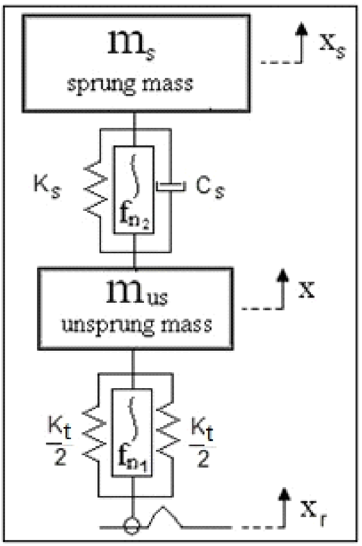

Fig. 1: Quarter Car Model

Quarter Car Parameters are –

$m_s = 40$ kg, $c_s = 414$ Ns/m $k_s = 124660$ N/m $m_{us} = 243$ kg, $c_{us} = 370$ Ns/m $k_{us} = 14671$ N/m

2.2. Optimization Using JAYA Algorithm

The algorithm always tries to get closer to success (i.e. reaching the best solution) and tries to avoid failure (i.e. moving away from the worst solution). The algorithm strives to becomevictorious by reaching the best solution and hence it is named as Jaya.

Jaya algorithm requires only the common control parameters and not the algorithm-specific Parameters. Common control parameters such as population size, number of generations and size arecommon to run any of the optimization algorithms and algorithm-specific parameters are specific and different algorithms have different specific parameters to control. The other evolutionary algorithms require control of common control parameters as well as their own algorithm-specific parameters. For example, genetic algorithm requires the tuning of specific parameters like crossover probability, mutation probability, selection operator, etc. in addition to tuning the common control parameters. Similarly, particle swarm optimization algorithm requires tuning of specific parameters like inertia weight, social and cognitive factors in addition to the tuning of common control parameters. Thus, the burden of tuning of control parameters is comparatively less in Jaya algorithm as it requirestuning of only the common control parameters. However, unlike two phases (i.e. teacher phase andlearner phase) of the TLBO algorithm, the Jaya algorithm has only one phase and it is comparatively simpler to apply. The working of Jaya algorithm is is explained in Fig 2.

$$XX'(jj,k,ii) = XX(jj,k,ii) + r1,jj,ii(XXjj(,best,ii) - XX(jj,k,ii)) - r2,jj,ii(XXjj,worst,ii) - XX(jj,k,ii)) \qquad (2)$$

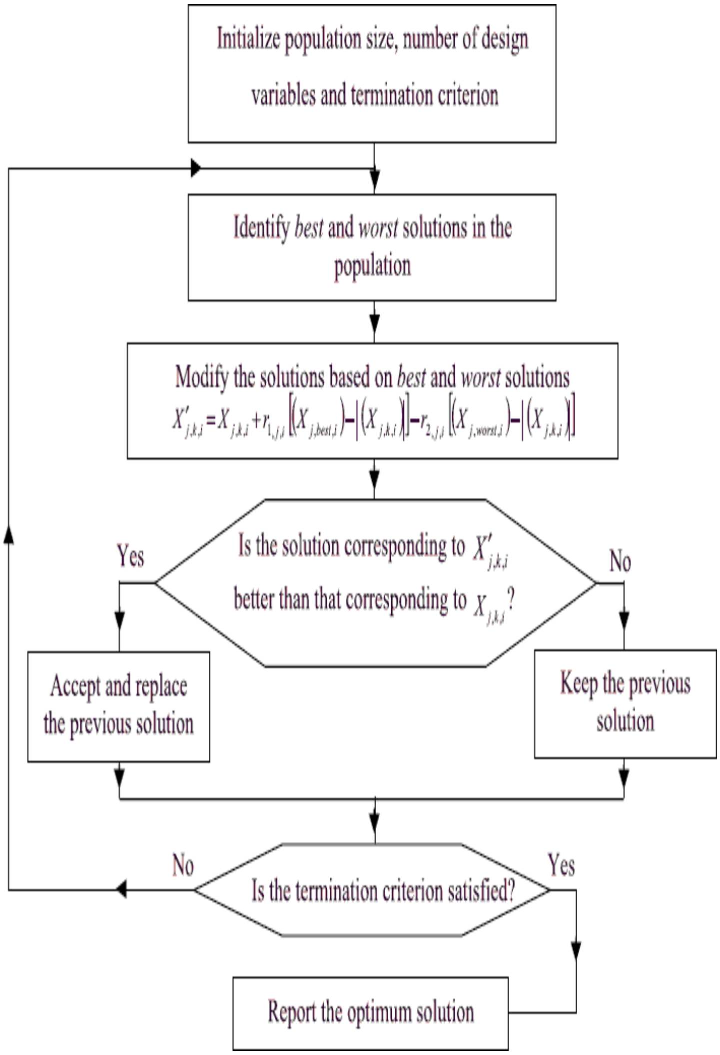

Fig.2: Flowchart of Jaya algorithm

2.3. Optimization of Quarter Car Suspension System

Modelling of automotive suspension is of great interest for automotive and vibration engineers. Vehicles ride quality is prime concern for the engineers when a vehicle passes over the speed bump. For our analysis 2 DOF quarter car model has been developed. Refer Fig. 3.

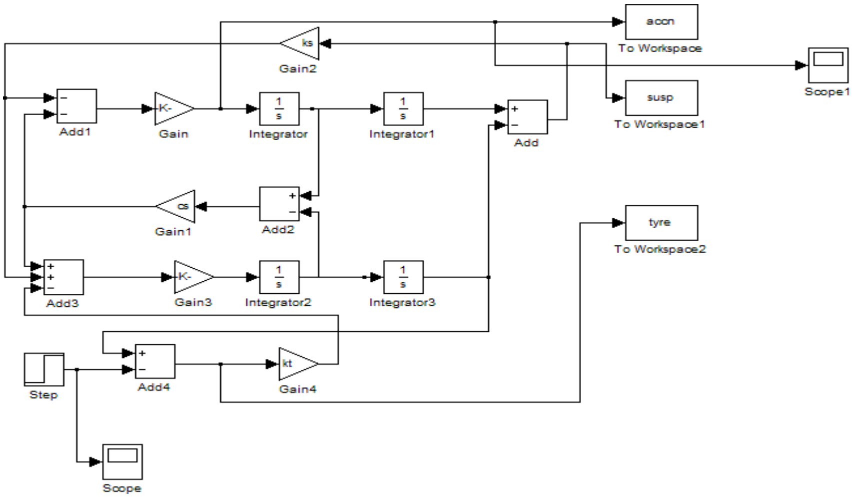

Fig.3 Model using Matlab

2.4. Quarter Car Test Rig

The functional ability of the suspension system test rig can be extended to large scale, because it provides the perfect platform to conduct different vibration testing's. Almost all the parameters can be measured using this test rig provided necessary instrumentation and sensorsare attached to its different components. This test rig actually simulates the road conditions.

To measure the various performance parameters like vertical acceleration, frequency of suspension vibration. The optimized values can be checked and verified actually. The electronic sensors like accelerometer can give different values which can be further converted to different parameters like comfort and stability of suspension. Refer Fig. 4.

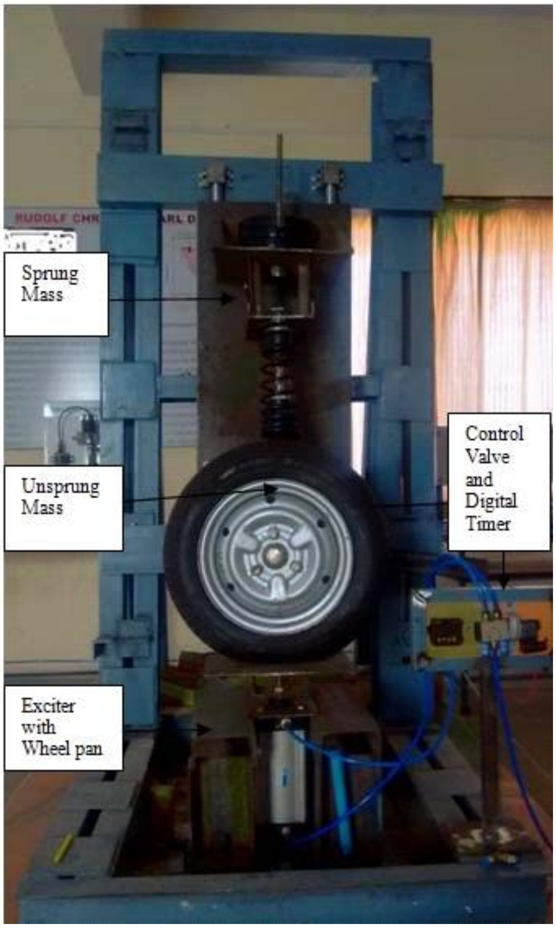

Fig. 4: Quarter Car Test Rig

3. Results and Discussions

The mathematical model is modelled in matlab/simulink environment and the optimization iscarried out as discussed in section 2 using JAYA algorithm. The optimal parameters obtained and the tested on test rig using the modified suspension spring.

3.1. Spring Design and Specification

Mean spring diameter (D)=80mm, Load on spring (f)=1500N, Modulus of elasticity in shear (G)=79500 MPa,

Number of active (n)=6.6, Total no of coils (n_t)=8.1, Free length (L_o)=2.85m, Solid length (l_s) =68.85mm, Pitch (P)=41.43mm

Natural frequency (f_n) = 71.63Hz, Volume = 0.0001155m^3, Density =7850 kg/m^3,Weight = 0.9070kg

Current design: Spring (C) = 9.4117, Wire diameter (d) = 8.5, Spring stiffness (K) = 15.3510 N/mm

Spring stiffness after optimization
k_{opt} = 10.832 N/mm

3.2. Testing Results

The Accelerometers were fixed in their positions and the excitations were given to the set up.The readings were recorded with the FFT and then transferred to the PC for analysing the results.

The results are taken to frequency is as follows

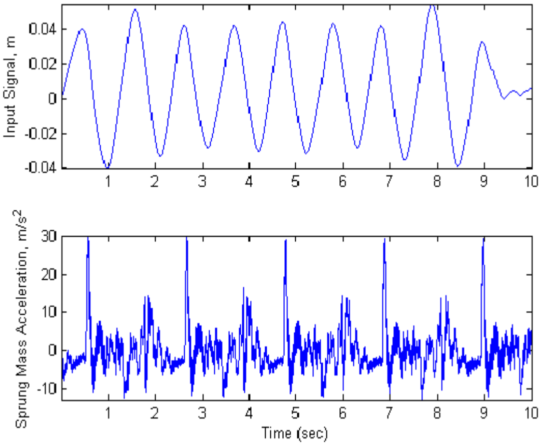

Fig.5. Un-Optimize, Freq. =2 Hz

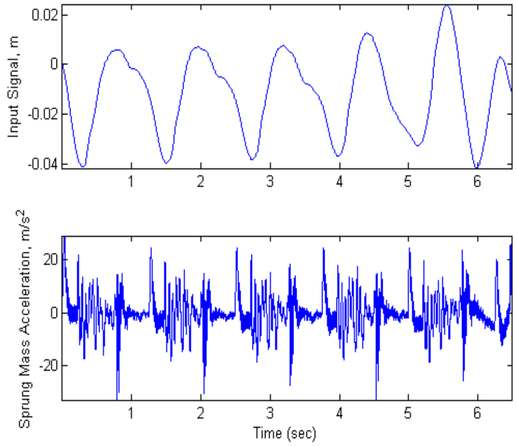

Fig.6: Optimize Freq. =2 Hz

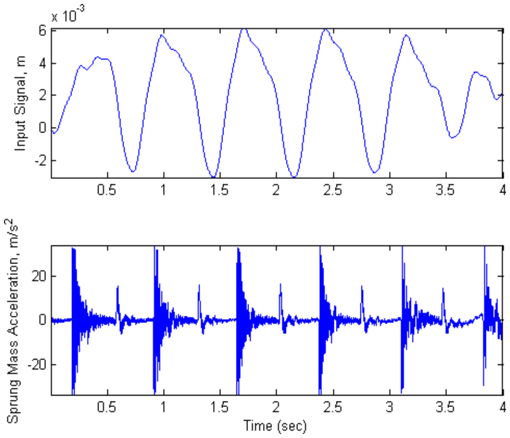

Fig.7: Un-Optimize Freq. =3.33 Hz

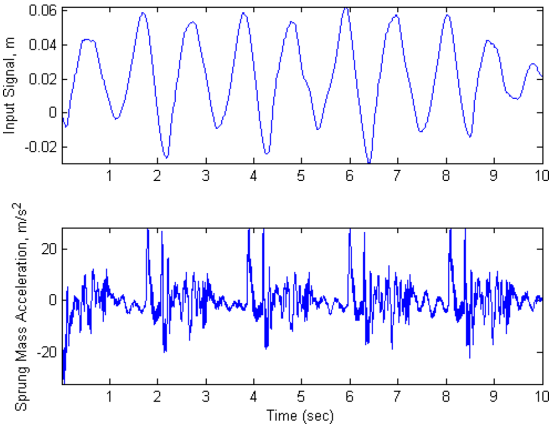

Fig.8: Optimize Freq. =3.33 Hz

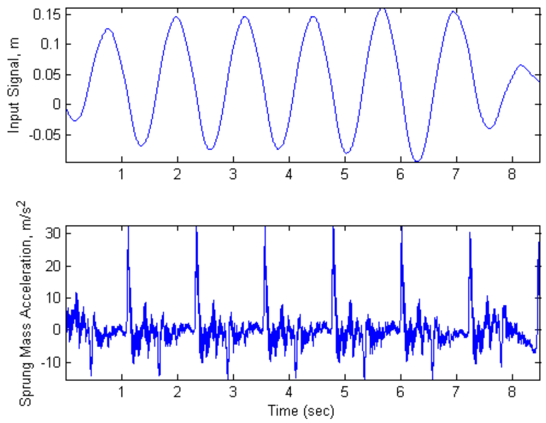

Fig.9 Un-Optimize Freq. =4 Hz

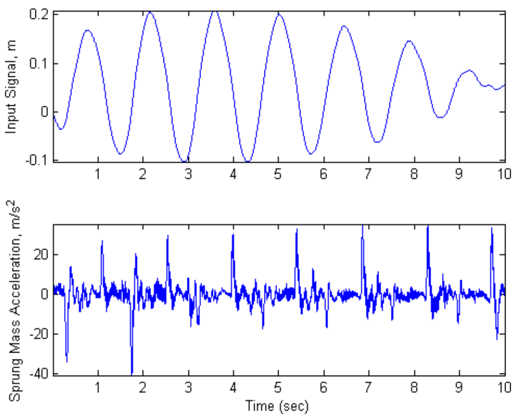

Fig.10 optimize Freq. = 4 Hz

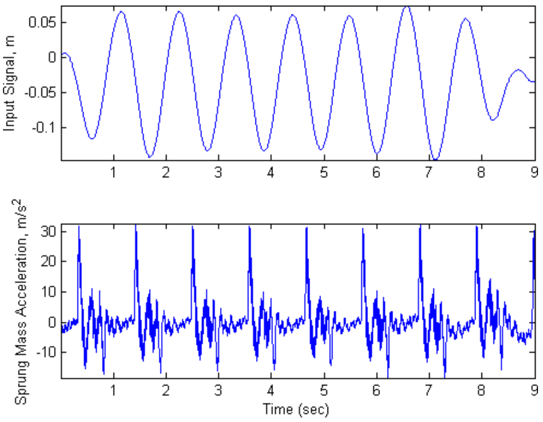

Fig.11: Un-Optimize Freq. =5 Hz

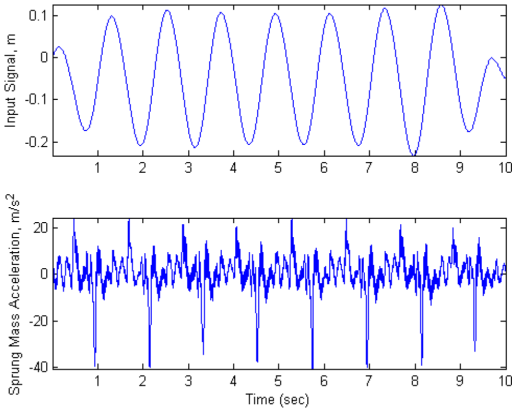

Fig.12: Optimize Freq. =5 Hz

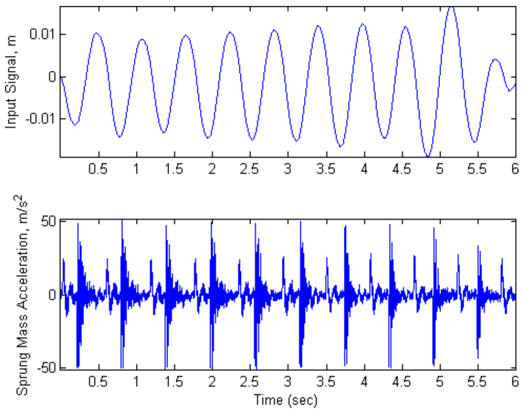

Fig.13 Un-Optimize Freq. =6.25 Hz

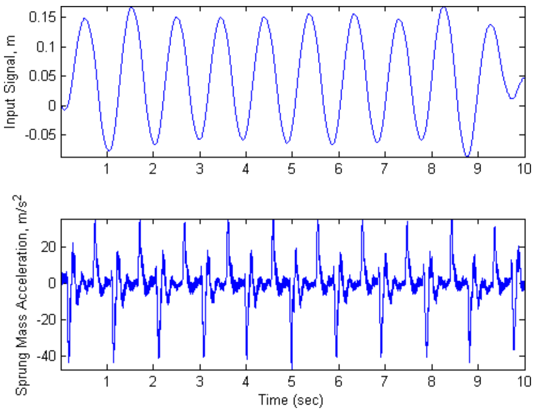

Fig.14 Optimize Freq. =6.25 Hz

Fig 5 – Fig 14 shows time domain results of optimized and un-optimized passive suspensionsystem. Figures shows time histories of sprung mass acceleration.

From Fig 5, Fig. 6 and Table 2 it is observed that for 2 Hz frequency input, there is 14% reduction in RMS sprung mass acceleration in case of optimized system and also has less maximum sprung mass acceleration as compared to un-optimized system. From Fig , Fig. 8 and Table 2 it is observed that for 3.33 Hz frequency input, there is 17% reduction in RMS sprung mass acceleration in case of optimized system and also has less maximum sprung mass acceleration as compared to un-optimized system. From Fig. 9, Fig. 10 and Table 2 it is observed that for 4 Hz frequency input, there is 17% reduction in RMS sprung mass acceleration in case of optimized system and also has less maximum sprung mass acceleration as compared to un-optimized system.

From Fig 11, Fig. 12 and Table 2 it is observed that for 5 Hz frequency input, there is 15% reduction in RMS sprung mass acceleration in case of optimized system and also has less maximum sprung mass acceleration as compared to un-optimized system. From 13, Fig. 14 and Table 2 it is observed that for 6.25 Hz frequency input, there is 11% reduction in RMS sprung mass acceleration in case of optimized system and also has less maximum sprung mass acceleration ascompared to un-optimized system.

Table.1 Result Table - Un-optimize and Optimize RMS Acceleration

SN	Frequency (Hz)	RMS ACCELERATION (m/s^2)			MAXIMUM ACCELERATION (m/s^2)	
		Un-optimize	optimize	Percentage (%)	Un-optimize	Optimize
1	2	6.8802	5.9130	14.05	33.0199	30.0844
2	3.33	6.7910	5.6030	17.49	32.3470	31.9521
3	4	6.9146	5.7279	17.16	40.5499	32.7095
4	5	8.2734	6.9600	15.87	40.6630	32.6631
5	6.25	11.1987	9.8860	11.72	47.4776	42.1546

4. CONCLUSION

In this paper, a mathematical model of passive quarter car suspension system is successfully presented. The mathematical model is then modeled in Matlab/Simulink environment and optimized using JAYA algorithm

Also the quarter car suspension system test rig is studied and simulated at 2 to 6 Hz frequencies. A good agreement is observed between mathematical model and quarter car suspension test rig. It is observed that 11% to 17% reduction in RMS sprung mass acceleration is observed in case optimized system. Also maximum sprung mass is observed on lower side in case of optimized suspension system. Overall optimized suspension system improved ride comfort.

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