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Optimization of Vehicle Suspension System Using Genetic Algorithm

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***Abstract*—The vehicle suspension system is one of the main design factors in the automobile industry that can exponentially increase the level of customers comport and satisfaction. Various design strategies can be used to get optimum values for the various parameters in the suspension system. In this paper, a passive vehicle suspension system was modeled, and the system was optimized using Genetic Algorithm (GA) optimization technique. The GA is based on natural evolution and is successfully applied to various real-world problems. The variance of the dynamic load resulting from the vibrating vehicle is taken as the performance measure (i.e., objective function) of the suspension system. During the application of GA, first appropriate mutation rate, crossover rate, and population size were evaluated which were used to calculate optimum values for the parameters in the suspension system. The optimum values for the suspension system correspond to minimum values of the settling time and maximum overshoot and thus helps in decreasing the effect of the dynamic loads by reducing the vehicle vibration.**

Keywords-genetic algorithm; optimum suspension parameters; passive system; vehicle suspension system

I. Introduction

The main purpose of the vehicle suspension system is to separate the wheels of the vehicle from the vehicle body and rectify the uncomfortable jerks that the passenger can get due to the road roughness. Any basic suspension system will contain a spring element for storing the energy due to the road roughness and a damper to restrict the sudden expansion of the spring. Due to the recent development in the automobile industry, the suspension system has increased both the comfort and security of the passengers [1-7]. The passive suspension system is not providing efficient vibration isolation in the whole frequency range due to its fixed vibration isolation parameters. Due to this reason many researchers are working on the active and semi-active suspension system. Various control strategies and controllable damper are used in the active and semi-active suspension system to provide the riding comfort at all the frequencies. The main drawbacks of the active and semi-active suspension systems due to which these two types of suspension systems are not widely used in automobile industry are large energy consumption and bad reliability [8-16].

In order to have maximum possible riding comfort and security, there is a need of calculating the optimum values for the suspension parameters. Various experimental studies are performed in the literature to achieve the optimum suspension system parameters. The recent optimization techniques can be more efficient in calculating the optimum values for the suspension parameters. Genetic algorithm (GA) is widely used in literature and is one of the very efficient methods for optimization [17-20]. GA is a general-purpose search algorithm which uses the principles inspired by natural genetic populations to evolve solution to the problem. The basic idea is to maintain a population of chromosomes, which represents the candidate solutions to the concrete problem that evolves over time through a process of competition and controlled variation. Each chromosome in the population has an associated fitness to determine which chromosomes are used to form new ones in the competition process which is called selection. The new ones are created uses genetic operators such as cross over and mutation [20-24].

In this paper, optimum suspension system parameters are calculated using the GA optimization technique. The objective function used for the optimization is dependent on the variance of the dynamic load resulting from the vibrating vehicle. The optimum values of the suspension parameters calculated using the GA will help in the reduction of the settling time and the maximum overshoot and thus will increase the driver comfort, safety, and security.

The rest of the paper is organized as follows: Section II discusses the modeling of car suspension system. In section III, the objective function is explained which is to be minimized. The results and discussions are explained in Section IV. The paper is concluded in Section V.

II. Modelling of Car Suspension System

The suspension system for one wheel of a car can be illustrated as shown in Fig. 1. The mass of the vehicle is M and the mass of the wheel is m. The suspension spring has a constant K_1 and the tire has a spring constant K_2. The damping constant of the shock absorber is C, y is the input from the road, x_1 is the displacement response of the vehicle to the input y from the road, and x_2 is the displacement response of the tire due to the input y from the road. The shock absorber is shown in Fig. 2. The car suspension system can be shown by the simple model as shown in Fig.

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3 whereas the free body diagram of the model is shown in Fig. 4.

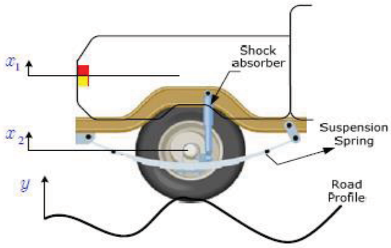

Figure 1. Car wheel suspension system.

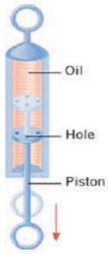

Figure 2. Shock absorber for the suspension system.

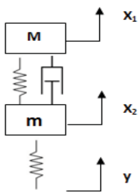

Figure 3. Suggested model of suspension system.

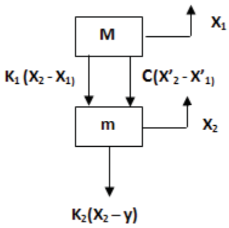

Figure 4. Free body diagram of suspension system.

The equations of the motion of the system described above are stated as:

$$Mx_1'' + C(x_1' - x_2') + K_1(x_1 - x_2) = 0 \qquad (1)$$

$$Mx_2'' + C(x_2' - x_1') + K_1(x_2 - x_1) + K_2(x_2 - y) = 0 \qquad (2)$$

The transfer function of the equations of motion can be obtained as:

$$G_1(s) = \frac{X_1(s)}{Y(s)} = \frac{K_2Cs + K_1K_2}{mMs^4 + (Cm+CM)s^3 + (K_1M + K_2M + K_1m)s^2 + CK_2s + K_1K_2} \qquad (3)$$

$$G_2(s) = \frac{X_2(s)}{Y(s)} = \frac{K_2Ms^2 + K_2Cs + K_1K_2}{mMs^4 + (Cm+CM)s^3 + (K_1M + K_2M + K_1m)s^2 + CK_2s + K_1K_2} \qquad (4)$$

MATLAB codes were used for finding the response of the system. The response of the suspension system is dependent on the values of the suspension system parameters (K_1, K_2, and C). The MATLAB codes were used to find the response of the suspension system for the two cases of suspension system with different values of the suspension system parameters (K_1, K_2, and C). The first case contains the suspension parameters from the work of Lu Sun et.al. [22] and the second case contains optimized values of the suspension parameters from the current optimization study.

Lu Sun et.al. [22] have performed a study in which GA is used for the optimization of vehicle suspension system. For the same case of the suspension system used in [22], the GA will be used in the current study to find the optimum values of the suspension system parameters. The time responses of the suspension system based on the suspension parameters from [22] will be compared with the time responses based on the optimized suspension system parameters calculated in the current study using the GA. The practical ranges (constraints) for the suspension parameters, i.e., spring stiffness (K_1), tyre stiffness (K_2), and damping stiffness (C) obtained from [22] are:

(1) $1\text{x}10^5\ N/m < K_1 < 3\text{x}10^6\ N/m$
(2) $1.5\text{x}10^6 N/m < K_2 < 2\text{x}10^6\ N/m$
(3) $0 < C < 3\text{x}10^5\ Ns/m$
Mass of the car = M = 4450 Kg
Mass of the tire = m = 550 Kg

The above-mentioned masses and ranges of the suspension system parameters will be used for calculating the optimum values of the suspension parameters in the current study.

III. Suspension System Optimization Using GA

Genetic algorithm is a general-purpose search algorithm which uses principles inspired by natural genetic populations to evolve solution to the problem [9, 10].The basic idea is to maintain a population of chromosomes, which represents the candidate solution to the concrete problem that evolves over time through a process of competition and controlled variation. Each chromosome in the population has an associated fitness to determine which chromosomes are used to form new ones in the competition process which is called selection. The new ones are created uses genetic operators such as cross over and mutation. The variance of the dynamic load resulting from the vibrating vehicle is used as the objective function to be minimized. The basic task will be to maximize the minimum value of zeta (ξ), as given below:

$$\xi = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}} \qquad (5)$$

where, σ and ω are real and imaginary parts of the Eigen value, respectively.

IV. Results and Discussion

As discussed previously the main objective of the current study is to find the optimum values for the suspension parameters (K_1, K_2, and C) that will correspond to minimum values of the settling time and maximum overshoot. With GA optimization technique, the population size was kept at 100 and maximum number of generations was taken as 1000. The system response is studied considering different probabilities of crossover such as: 0.78, 0.88, and 0.93 while 0.001 is taken for mutation.

With having the minimum and maximum values for the parameters to be optimized (provided in Section II) we first randomly generate 100 values for each of the three parameters within the allowable ranges. As given in equations (3) and (4), the suspension system is a 4^{th} order in denominator which will generate four Eigen values for each set of the suspension parameters (K_1, K_2, and C). The value of zeta (ξ) as defined in (5) is evaluated for each Eigen value and then minimum is stored in a vector for all the population size and thus on the basis of the objective function evaluation reproduction takes place in which a new population is formed on the basis of the fitness value of the individuals in the initial population.

Before implementing the proposed technique, some random values of suspension parameters are considered within the allowable range. These random values are given in Table I. The time response of the suspension system for the randomly assumed parameters is shown in Fig. 5. It can clearly be seen that the settling time is too long.

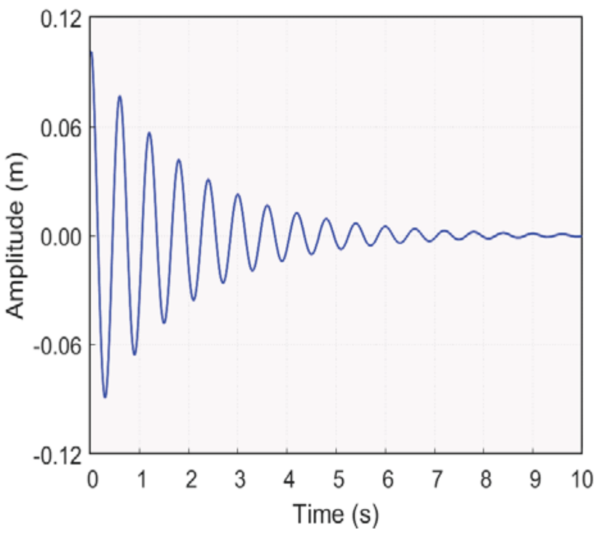

Figure 5. Time response of a suspension system with random suspension parameters.

In addition, the system response is studied considering the optimized values of suspension parameters which are tabulated in Table I. The time response of the system considering these values is shown in Fig. 6. It can be seen that the settling time is around four seconds.

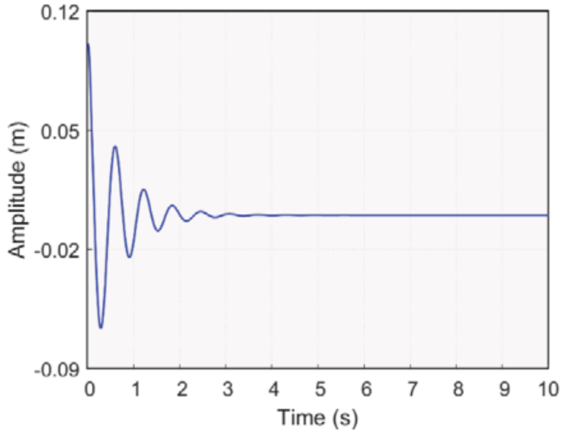

Figure 6. Time response of a suspension system with optimized parameters obtained from [22].

In this paper, GA optimization technique is used to calculate the optimum suspension parameters. The system parameters are optimized considering different crossover probabilities. The optimized suspension parameters considering these crossover probabilities are tabulated in Table II. Note that the mutation rate is kept constant, i.e., 0.001. The objective function evaluation for a crossover probability of 0.78 is shown in Fig. 7.

TABLE I. Suspension System Parameters

Parameters	Random	From [22]
K_1	$1.0x10^6$	$6.2218x10^5$
K_2	$1.0x10^6$	$1.70549x10^6$
C	$2.0x10^4$	$2.6582x10^5$

TABLE II. Optimized Suspension System Parameters Using Genetic Algorithm

Probability	0.78	0.88	0.93
K_1	$2.0109x10^6$	$1.3419x10^6$	$1.6430x10^6$
K_2	$1.7339x10^6$	$1.7459x10^6$	$1.9671x10^6$
C	$8.5863x10^4$	$1.5372x10^5$	$1.8397x10^5$

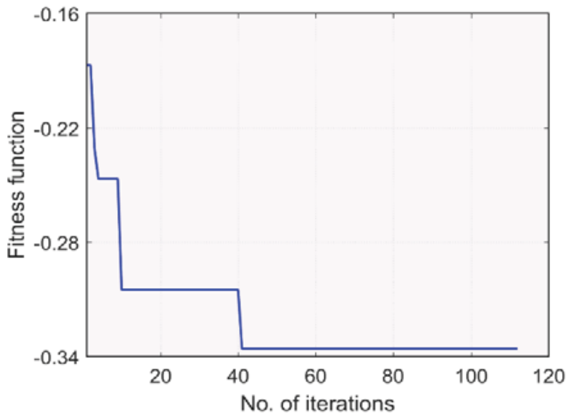

Figure 7. Objective function evaluations for a mutation rate of 0.001 and a crossover probability of 0.78.

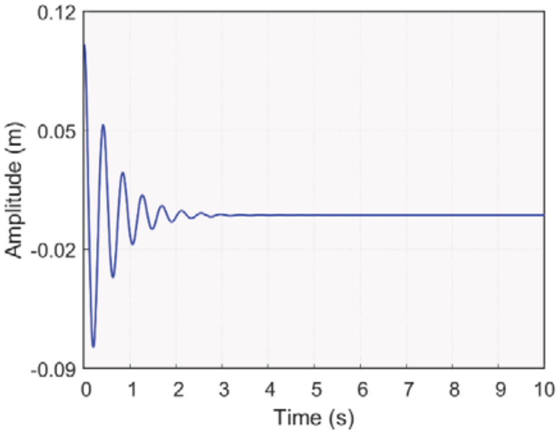

Figure 8. Time response of a suspension system optimized with mutation rate of 0.001 and a crossover probability of 0.78.

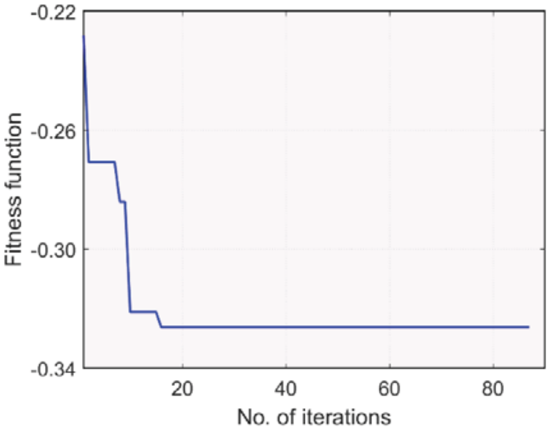

Figure 9. Objective function evaluations for a mutation rate of 0.001 and a crossover probability of 0.88.

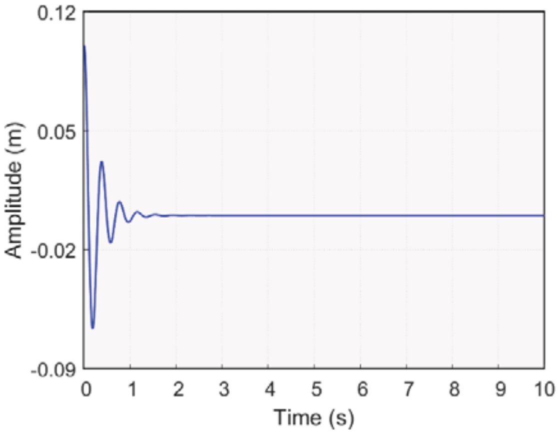

Figure 10. Time response of a suspension system optimized with mutation rate of 0.001 and a crossover probability of 0.88.

Moreover, the corresponding time response is shown in Fig. 8. The steady state response is achieved in almost three seconds. The objective function evaluation for a crossover probability of 0.88 is given in Fig. 9. It can be observed that the optimum solution is found earlier when crossover probability is set to 0.88. Furthermore, it can be seen from Fig. 10 that the settling time is reduced to two seconds when crossover probability is increased. Although there is no remarkable improvement in the peak amplitude, however, the settling time has been reduced significantly. Consequently, the oscillations and the corresponding peaks have been reduced.

Moreover, the objective function evaluation and time response are shown in Figs. 11 and 12, respectively. It can be seen from the above cases that the objective function converges rapidly as we increase the value of the crossover probability. Note that the settling time for the proposed technique is less than the one obtained from [22].

V. Conclusion

This study deals with the optimization of the suspension system parameters using Genetic Algorithm (GA). The suspension system optimization can be summarized as:

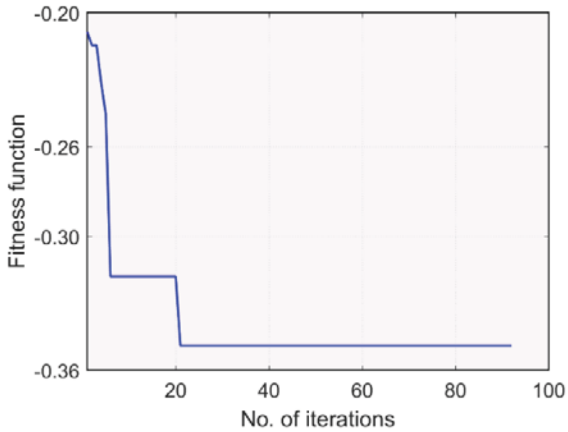

Figure 11. Objective function evaluations for a mutation rate of 0.001 and a crossover probability of 0.93.

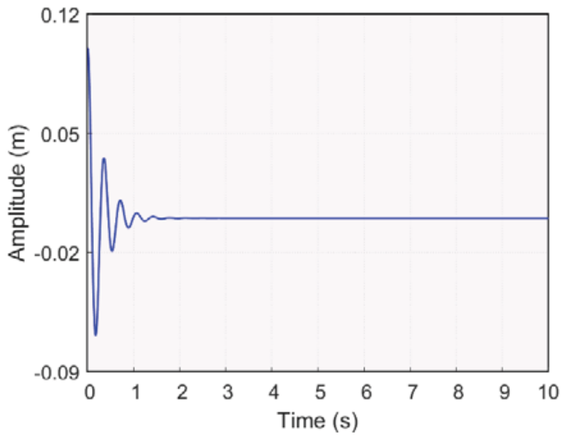

Figure 12. Time response of a suspension system optimized with mutation rate of 0.001 and a crossover probability of 0.93.

- Optimized values of the suspension parameters will give less overshoot and settling time and will correspond to high level of the passenger comfort.

- The objective function converges rapidly with an increase in the value of the crossover probability with constant mutation rate while using the GA for the optimization of the suspension system parameters.
- The time domain response results show that the maximum overshoot and settling time decreases as the crossover probability increases at a constant mutation rate.
- For the same crossover over probability and mutation rate the settling time was compared with the work done in [22]. The comparison shows a good agreement, which shows the validity of our optimization technique.

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