ORIGINAL ARTICLES

Design of Optimal Linear Suspension for Quarter Car with Human Model using Genetic Algorithms

[1]Dr. Tantawy M. Farid, [2]Dr. Ashraf Salah and [3]Dr.Wael Abbas,

[1]Basic and Applied Science Department, Faculty of Engineering (Cairo bransh), Arab Academy for Science, Technology and Marine Transport,Cairo. Egypt.
[2]Engineering Automotive Dept., Faculty of Eng., Helwan Univ., Egypt
[3]Engineering Physics and Mathematics Department, Faculty of Engineering (Mataria), Helwan University, Cairo, Egypt.

ABSTRACT

Ride comfort is the most important demand in vehicle industry as it directly affects the sales amount. For that reason a lot of effort had been made to improve ride comfort by isolating vehicle from road irregularities as much as possible. The desired objective is proposed as the minimization of a seat suspension deflection, seat body acceleration and human body head acceleration, by choosing optimal vehicle suspension parameters. This paper presents an optimization of a four-degrees-of-freedom (4-DOF) vehicle's human with seat suspension system using genetic algorithms (GA) to determine vehicle suspension parameters to achieve the best comfort of the human body. Maximum allowed vertical acceleration of the human body and the suspension working space were used as constrained limits in this study. The genetic algorithm is applied to solve the optimization problem. The optimization results are compared through step and sinusoidal excitation of the seat suspension system for the optimal and currently used suspension systems. In case of sinusoidal profile excitation, results showed that root mean square (RMS) acceleration of the driver, seat suspension working space and sprung mass are reduced by about 21%, 21.5% and 20.3%, respectively. At step profile excitation, RMS acceleration of the driver, seat suspension working space and sprung mass are reduced by about 24%, 24.98% and 7.15%, respectively. The optimal design parameters of the suspension systems obtained are k_s = 10039 N/m and c_s = 900 N.s/m in case of sinusoidal input and k_s = 10030 N/m and c_s = 913 N.s/m in case of step input, respectively.

Key words: Biodynamic response, Ride-comfort, Simulation, Genetic algorithms

Introduction

Today, a rebellious race is taking place among the automotive industry so as to produce highly developed models. One of the performance requirements is advanced suspension systems which prevent the road disturbances to affect the passenger comfort while increasing riding capabilities and performing a smooth drive. While the purpose of the suspension system is to provide a smooth ride in the car and to help maintain control of the vehicle over rough terrain or in case of sudden stops. Increasing ride comfort results in larger suspension stroke and smaller damping in the wheel hop mode, according to Chen H. *et al.*, (2005).

The vibrations cause the operator's whole body to vibrate, as opposed to just one part of their body, says their hand or foot. Harmful effects of whole-body vibration are experienced when the exposure time is longer than the recommended standard set by ISO 2631-1., (1997). The reported data on biodynamic responses of the seated and standing human body exposed to whole-body vibration along different directions and the associated experimental conditions are systematically reviewed by Rakheja *et al.*, (2010), in an attempt to identify datasets that are likely to represent comparable and practical postural and exposure conditions. The vibration isolation efficiency of seating has been evaluated by Paddan and Griffin, (2002), in 100 work vehicles in 14 categories. They concluded that the severity of whole-body vibration exposures in many work environments can be lessened by improvements to seating dynamics. Stein *et al*., (2008), described a simplified simulation of two configurations of the fore-and-aft seat suspension system based on the laboratory measurements of the seat vibration isolation performance. The optimization study shows the attainable vibration mitigation limits for a horizontal suspension system. A 7-DOF vehicle's driver model with seat suspension system was presented by Wael el al., (2010). A genetic algorithm is applied to search for the optimal parameters of the seat in order to minimize seat suspension deflection and driver's body acceleration to achieve the best comfort of the driver. The simulation results were compared with the ones of the passive suspensions through step and sinusoidal excitation of the seat suspension system for the currently used suspension systems.

Corresponding Author: Dr. Tantawy M. Farid, Basic and Applied Science Department, Faculty of Engineering (Cairo bransh), Arab Academy for Science, Technology and Marine Transport,Cairo. Egypt.
E-mail: tantmfarid@hotmail.com

On the other hand, vehicle suspension systems aim to improve the vehicle performance which involves: Ride comfort, handling, road holding, suspension deflection, and static deflection. Lu Sun (2002), presented an optimum concept to design ''road-friendly'' vehicles with the recognition of pavement loads as a primary objective function of vehicle suspension design. The results showed that tires with high air pressure and suspension systems with small damping will lead to large tire loads. The parameter sensitivity analysis of a passenger/seat model that can be used for ride comfort assessments was discussed by Brogioli *et al.*, (2011). The most important conclusion of their research is that the parameters referring to posture have proved to influence ride comfort to a great extent. Other relevant but less important parameters are: the stiffness and damping of the seat, the geometry of the seat, the size and inertia properties of the body segments, and the stiffness and damping of the different parts of the human body. A generalized nonlinear model is formulated by Bouazara *et al.*, (2006), for the dynamic analysis of suspension seats with passive, semi-active and active dampers. It is concluded that the comfort performance of a suspension seat with semi-active and active dampers can be considerably enhanced by 20–30%. The spring and damper settings that will ensure optimal ride comfort of an off-road vehicle, on different road profiles and at different speeds has been investigated by Uys *et al.*, (2007). It is found that optimizing for a combined driver plus rear passenger seat weighted root mean square vertical acceleration rather than using driver or passenger values only, returns the best results.

For efficiency, genetic algorithm is employed to search for the parameters like damping ratio and spring constant to achieve an optimum trade off among ride comfort, handling quality, and suspension stroke simultaneously for random input. A dynamic model of an on-highway truck seat is proposed by Hassanin *et al.*, (2008), to improve a highway truck seat. Genetic algorithms are used to obtain the coefficients of a seat suspension system controller parameters. The results showed that an active suspension using genetic algorithms has successfully managed to improve all the dynamic performance parameters of the truck seat with minimum actuator force. GA optimization is used by Baumal *et al.*, (1998), to determine both the active control and passive mechanical parameters of a vehicle suspension system, to minimize the extreme acceleration of the passenger's seat, subjected to constraints representing the required road-holding ability and suspension working space. A complete study on lumped parameter models for seated human subjects without backrest support under vertical vibration excitation has been carried out by Liang and Chiang (2006), based on analytical study and experimental validation. An optimization of a 4-DOF quarter car seat and suspension system was presented by Gündoğdu., (2007), using genetic algorithms to achieve the best performance of the driver. The optimization results were compared through step and frequency responses of the seat and suspension system for the optimum and currently used suspension systems. Comparatively better results were obtained from the optimized system in terms of resonance peaks and vibration dose value.

The design of a passive vehicle suspension system was handled by Sun *et al.*, (2007), in the framework of nonlinear optimization using a quarter-car model. The performance was measured by the aid of a GA which is applied to solve the nonlinear optimization problem to achieve the optimum design parameters of the suspension systems. A genetic algorithm method is applied to the optimization problem of a linear 1-DOF vibration isolator mount and the method is extended to the optimization of a linear quarter car suspension model was mentioned by Alkhatib and *et al.*, (2004). Although the systems are linear, it is difficult to find such optimal relation analytically. The GA method increases the probability of finding the global optimum solution and avoids convergence to a local minimum which is a drawback of gradient-based methods.

The GA is used to solve the problem, and results were compared to those obtained by simulated annealing technique and found to yields similar performance measures. A control scheme for the active suspension in a 4-DOFs half-car model is presented by Hada *et al.*, (2007). A force cancellation control scheme is used to isolate the sprung and the unsprung masses. Road following springs are applied for the sprung mass to follow the trend of the road surface condition and to maintain the suspension stroke within a reasonable range.

On the other hand, whole-body vibration is harmful to humans because it excites the natural frequency of the body. Whole-body vibration has many ill effects on the operators. Health effects can range from fatigue to permanent damage to the spine of the operator. Many studies have been conducted to link the exposure of whole-body vibration to common health problems experienced by operators of vibrating machinery. These studies were presented by (Gniady *et al.*,1991; Schwarze *et al.*,1998; Mehta *et al.*, 2000), to show the effects of whole-body vibration, and some debate whether the ISO standard is strict enough. Table 1 shows a number of vital body parts, and the corresponding natural frequencies.

1711

J. Appl. Sci. Res., 7(11): 1709-1720, 2011

Table 1: Natural frequencies of the human body.

Body Part	Natural Frequency (Hz)
Trunk	3-6
Eyeball	20-25
Chest	4-6
Thorax	3
Spine	3-5
Heart	4-5
Shoulders	2-6
Head	30
Stomach	4-7
Colon	20-25

Problem Description:

This paper is based on a 4-DOF human body developed by Wael *et al* (2010), with linear seat suspension - coupled with quarter car model. In this model, a genetic algorithm is applied to search for the optimal parameters of the car suspension in order to minimize car suspension deflection and driver's body acceleration to achieve the best comfort of the driver.

Mathematical model formulation:

Proposed Model:

This section is devoted to the mathematical modeling of the proposed model, including the biodynamic lumped human linear seat model coupled with quarter model of ground vehicles as illustrated in Fig. 1. It is assumed that the system does not vibrate in lateral or longitudinal directions, only subjects exposed to vertical vibration.
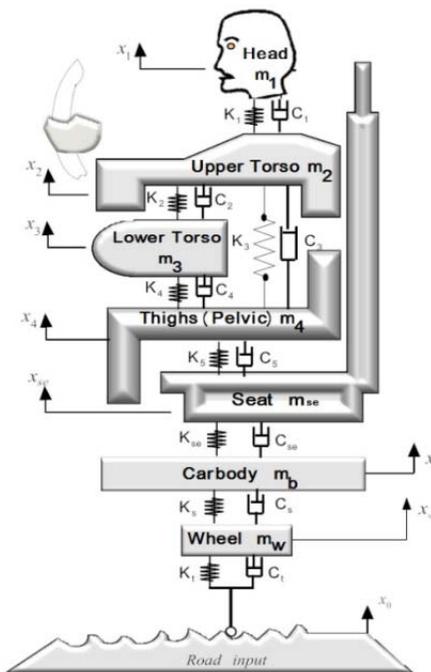
Fig. 1: Schematic diagram of biodynamic lumped human model coupled with quarter car model.

The human-body has a 4-DOF that proposed by Wael *et al.*, (2010). In this model, the seated human body was constructed with four separate mass segments interconnected by five sets of springs and dampers, with a total human mass of 60.67 kg. The four masses represent the following body segments: head and neck (m_1), upper torso (m_2), lower torso (m_3), and thighs and pelvis (m_4). The arms and legs are combined with the upper torso and thigh, respectively. The stiffness and damping properties of thighs and pelvis are (k_5) and (c_5), the lower torso are (k_4) and (c_4), upper torso are (k_2, k_3) and (c_2, c_3), and head are (k_1) and (c_1). Typical design parameters for the model are listed in Table II.

Table 2: Model Parameters

Mass (kg)	Damping coefficient (N.s/m)	Spring constant (N/m)
$m_1 = 4.17$	$C_1 = 310$	$k_1 = 166990$
$m_2 = 15$	$C_2 = 200$	$k_2 = 10000$
$m_3 = 5.5$	$C_3 = 909.1$	$k_3 = 144000$
$m_4 = 36$	$C_4 = 330$	$k_4 = 20000$
-	$C_5 = 2475$	$k_5 = 49340$
$m_{se} = 35$	$C_{se} = 150$	$k_{se} = 15000$
$m_b = 250$	$C_s = 980$	$k_s = 16000$
$m_w = 35$	$C_t = 0$	$k_t = 160000$

The equations of motion of the model are:

$$
\begin{cases}
m_1 \ddot{x}_1 = -c_1(\dot{x}_1 - \dot{x}_2) - k_1(x_1 - x_2), \\[2mm]
\begin{aligned}
m_2 \ddot{x}_2 &= c_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) - c_2(\dot{x}_2 - \dot{x}_3) \\
&- k_2(x_2 - x_3) - c_3(\dot{x}_2 - \dot{x}_4) - k_3(x_2 - x_4),
\end{aligned} \\[2mm]
\begin{aligned}
m_3 \ddot{x}_3 &= c_2(\dot{x}_2 - \dot{x}_3) + k_2(x_2 - x_3) - c_4(\dot{x}_3 - \dot{x}_4) \\
&- k_4(x_3 - x_4),
\end{aligned} \\[2mm]
\begin{aligned}
m_4 \ddot{x}_4 &= c_4(\dot{x}_3 - \dot{x}_4) + k_4(x_3 - x_4) + c_3(\dot{x}_2 - \dot{x}_4) \\
&+ k_3(x_2 - x_4) - c_5(\dot{x}_4 - \dot{x}_{se}) - k_5(x_4 - x_{se}),
\end{aligned} \\[2mm]
\begin{aligned}
m_{se} \ddot{x}_{se} &= c_5(\dot{x}_4 - \dot{x}_{se}) + k_5(x_4 - x_{se}) \\
&- c_{se}(\dot{x}_{se} - \dot{x}_b) - k_{se}(x_{se} - x_b),
\end{aligned} \\[2mm]
\begin{aligned}
m_b \ddot{x}_b &= c_{se}(\dot{x}_{se} - \dot{x}_b) + k_{se}(x_{se} - x_b) - c_s(\dot{x}_b - \dot{x}_w) \\
&- k_s(x_b - x_w),
\end{aligned} \\[2mm]
\begin{aligned}
m_w \ddot{x}_w &= c_s(\dot{x}_b - \dot{x}_w) + k_s(x_b - x_w) - c_t(\dot{x}_w - \dot{x}_o) \\
&- k_t(x_w - x_o).
\end{aligned}
\end{cases}
\tag{1}
$$

Input Profile Excitations:

The excitation input from the road is transmitted to the vehicle floor. For the simplification of the dynamic modeling, it is assumed that there exists only the vertical motion of the vehicle. Both pitching and rolling motions are ignored in this study.

In this work, two types of the input profiles excitation are adopted to evaluate the proposed system. The sinusoidal profile is firstly used, which is described by:

$$
x_b = A \sin(\omega t)
\tag{2}
$$

where, $\omega = \frac{\pi v_c}{D}$, and A (0.035 m) is the hump height. D (0.8 m) is the width of the hump, and v_c is the vehicle velocity. This excitation assumed that the vehicle model travels with a constant velocity of 20 km/h (5.55 m/s). The second types of road is step profile. The step height was 0.035 m applied instantaneously.

Optimal linear Seat suspension Design:

Numerical Simulations:

Displacement, velocity, and acceleration of the model in terms of time domain are obtained by solving equation, Equation 1, using MATLAB software ver. 7.12 (R2011a), dynamic system simulation software, Simulink. The initial conditions are assumed at equilibrium position. Fig. 2 shows the main Simulink model of the suspension with human-body system.

Optimization via Genetic Algorithms:

In this section, optimization software based on stochastic techniques search methods, Genetic algorithm

1713

J. Appl. Sci. Res., 7(11): 1709-1720, 2011

(GA) is a global search method based on the principle of natural section, which are related to the evolution in nature. "Survival of the fittest", Darwin's principle of natural section, promoted the idea of mimicking the natural section and using in the artificial life possible solutions (individuals).
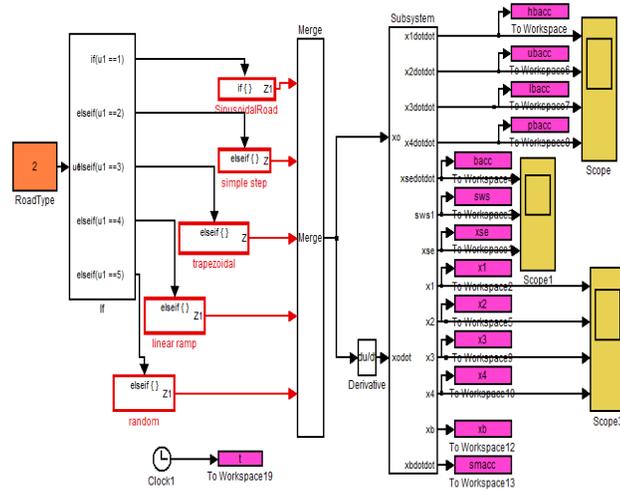

Fig. 2: Seat suspension with human-body system: Main Simulink model.

Genetic Algorithms (GAs), are employed to search for the optimal linear parameters of the car suspension to achieve the best comfort of the driver. The upper boundaries of car suspension parameters are selected based on previous studies. Table III shows the genetic algorithms parameters and their selected values.

Table 3: Genetic Algorithm Parameters

GA parameters	Value
Population size	50
No of generations	1000
Fitness scaling	Rank
Crossover technique	Heuristic
Probability of crossover	0.8
Mutation technique	Uniform
Generation gap	0.9
Lower boundary	900-10000
Upper boundary	2500-20000
Objective function accuracy	$1e^{-15}$

Since the health of the driver is as important as the stability of the car, the desired objective is proposed as the minimization of a multi-objective function formed by the combination of not only car suspension working space *(sws=x_b-x_w)* but also the head acceleration ($\ddot{x}_1$), and seat mass acceleration ($\ddot{x}_{se}$). This study used the classical weighted sum approaches to solve a multi-objective optimization problem as equation:

$$OBJ = w_1.(\ddot{x}_1) + w_2.(sws) + w_3.(\ddot{x}_{se})\qquad(3)$$

Where, w_1, w_2 and w_3 are weighting factors to emphasize the relative importance of the terms. Table IV shows weighting factors used in excitation inputs.

Table 4: Weighting factors

Weight	w_1	w_2	w_3
Excitation input	0.5	0.3	0.2

Optimization Procedure:

First, the defined bounds of the design variables and initial suspension design variables k_s and c_s are created by using random samples. Then k_s and c_s are passed into the proposed model to solve for the dynamic response (displacement, velocity, and accelerations values) of the system. The population is then coded into chromosomes, a binary representation of a solution (consisting of the components of the decision variables known as genes in the genetic algorithm). The whole population of chromosomes represents a generation. An

1714

J. Appl. Sci. Res., 7(11): 1709-1720, 2011

evaluation function in terms of its fitness, here, fitness is a numerical value describing the probability for a solution to survive and reproduce. Only a portion of the population (survivors or solutions with higher fitness values) is selected for creating a new population (offspring production). This new population is created by using a crossover operator.

Crossover is a procedure for exchanging pieces of chromosome data with one another. Crossover allows genes that generate good fitness to be preserved and enlarged in a new generation of the population. Mutation is a genetic operator and it randomly flips the bits of an offspring's genotype. This is equivalent to perturbing the mated population stochastically. Mutation prevents the population from homogenizing in a particular set of genes such that any gene in a generation has a certain probability (determined by the mutation rate) of being mutated in future generations.

The new population is being mixed up to bring some new information into this set of genes, and this needs to happen in a well-balanced way. Once the new generation is created, the aforementioned steps are repeated until some convergence criteria are satisfied, such as running time and fitness. The overall technique is summarized in a flowchart given in Fig. 3.
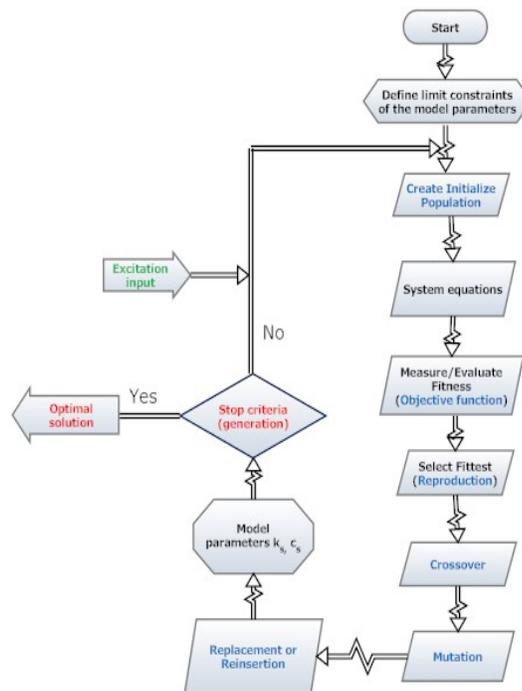

Fig. 3: Design process using GA.

Results and Discussion

The GA method increases the probability of finding the global optimum solution and avoids convergence to a local minimum which is a drawback of gradient-based methods. Computer simulations are performed for three cases of different weighted factors in order to obtain the required dynamic performance of the proposed design of the seat. The results are generated when excited by an artificial generated step and sinusoidal inputs, respectively.

The optimal vehicle parameters for the present model were determined and the results with GA method were compared with passive model. The design results from the passive and optimal suspensions are tabulated in table V. Simulation is performed using driver-seat-car data illustrated in Table I, for the defined vehicle excitation inputs.

The optimal car suspension parameters for the present model were determined by genetic algorithms method, compared with the current passive parameters and tabulated in Table V.

Table 5: The design results from the GA program

Seat suspension setting	Currently used	GA optimization	
		Sinusoidal	Step
K_s	16000	10039	10030
C_s	980	900	913

1715

J. Appl. Sci. Res., 7(11): 1709-1720, 2011

Figs. 4 and 5 present the history of some selected response components of the human-body model for sinusoidal input excitation. In particular the results in Fig. 4 depict the acceleration histories obtained at the different model components: head, upper torso, lower torso, pelvic, seat, and sprung mass, respectively. The maximum amplitude of acceleration determined in all seven components is increased originally and then decreased. Whereas, Fig. 5 shows the displacement histories obtained at the same model components. On the other hand, Figs. 6 and 7 present the history at the same parts that determine response of the human-body model, in case of step input excitation.

In order to verify the validity of the results, the GA were compared to those obtained by passive suspension for head, upper torso, lower torso, pelvic, seat, and sprung mass using two different excitation input: sinusoidal and step inputs.

The results of tables VI and VII indicate that the RMS percentage improvement of the driver's vertical acceleration is about 21% and 24% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively. The RMS percentage improvement in seat suspension working space is about 21.5% in case of both sinusoidal and step excitation inputs.

The reduction of the driver's vertical displacement peak is about 19% and 17% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively. The reduction of the seat suspension working space is about 19.6% and 17.5% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively.

In addition, the RMS percentage improvement of sprung mass was reduced by about 20% and 7% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively. The reduction of peak values of sprung mass are about 22.5% and 20%, in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively.

Based on the application of genetic algorithms to the optimal design of vehicles suspension, it was found that all parts of human-body acceleration, seat suspension working space, and sprung mass which were reduced by about 21% in case of both sinusoidal and step excitation. The reductions of peak values are more that 19% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs.

Table 6: RMS percentage improvement results

		RMS acceleration					
		Head	Upper torso	Lower torso	Pelvic	Seat	Sprung mass
Sinusoidal	Passive	2.093	2.080	2.140	1.964	1.572	3.402
	GA	1.645	1.630	1.678	1.539	1.234	2.710
	% Improvement	21.40	21.62	21.57	21.65	21.51	20.34
Step	Passive	1.389	1.365	1.385	1.333	1.169	1.624
	GA	1.045	1.035	1.051	1.008	0.877	1.508
	% Improvement	24.76	24.17	24.11	24.38	24.98	7.15

Table 7: Peak values reduction

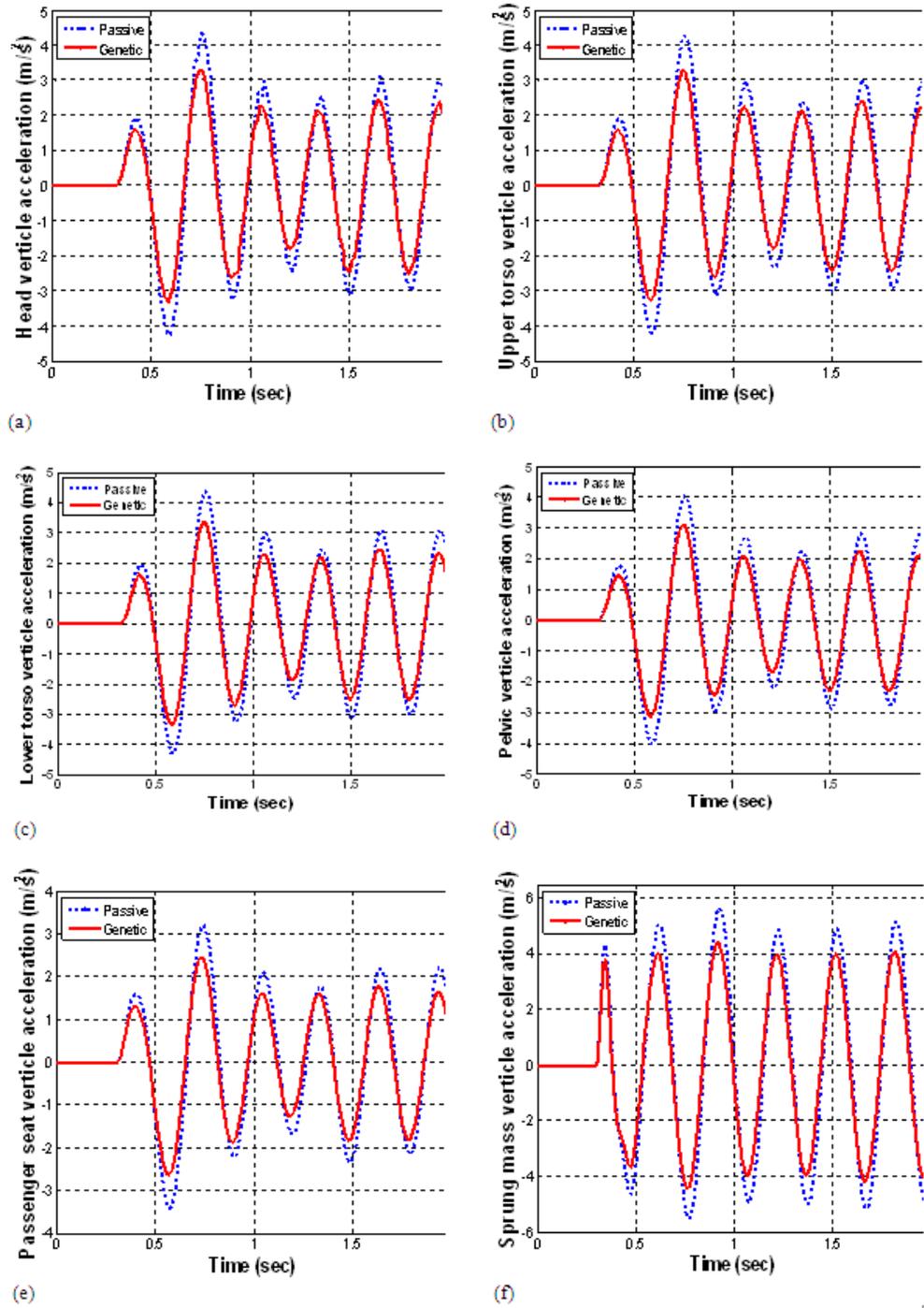|		Sinusoidal			Step		
		Maximum overshoot		% Reduction of Peak overshoot	Maximum overshoot		% Reduction of Peak overshoot
		Passive	GA		Passive	GA	
Acceleration (m/s²)	Head	4.333	3.2925	24.01	2.4426	1.8084	25.26
	Upper torso	4.270	3.2616	23.61	2.4262	1.7897	26.23
	Lower torso	4.3872	3.3460	23.73	2.4493	1.8733	23.52
	Pelvic	4.0542	3.0919	23.74	2.3498	1.6823	28.40
	Seat	3.2145	2.4588	23.50	1.9308	1.5235	21.10
	Sprung mass	5.6748	4.4002	22.46	7.7226	7.3393	4.97
Displacement (m)	Head	0.0230	0.0186	19.13	0.0490	0.0403	17.76
	Upper torso	0.0229	0.0185	19.21	0.0489	0.0403	17.59
	Lower torso	0.0232	0.0187	19.39	0.0493	0.0405	17.85
	Pelvic	0.0224	0.0181	19.19	0.0484	0.0398	17.77
	Seat	0.0204	0.0164	19.60	0.0451	0.0372	17.51
	Sprung mass	0.0178	0.0142	20.22	0.0318	0.0261	17.92

Fig. 4: Sinusoidal acceleration histories: (a) head, (b) upper torso, (c) lower torso, (d) pelvic, (e) seat, and (f) sprung mass.
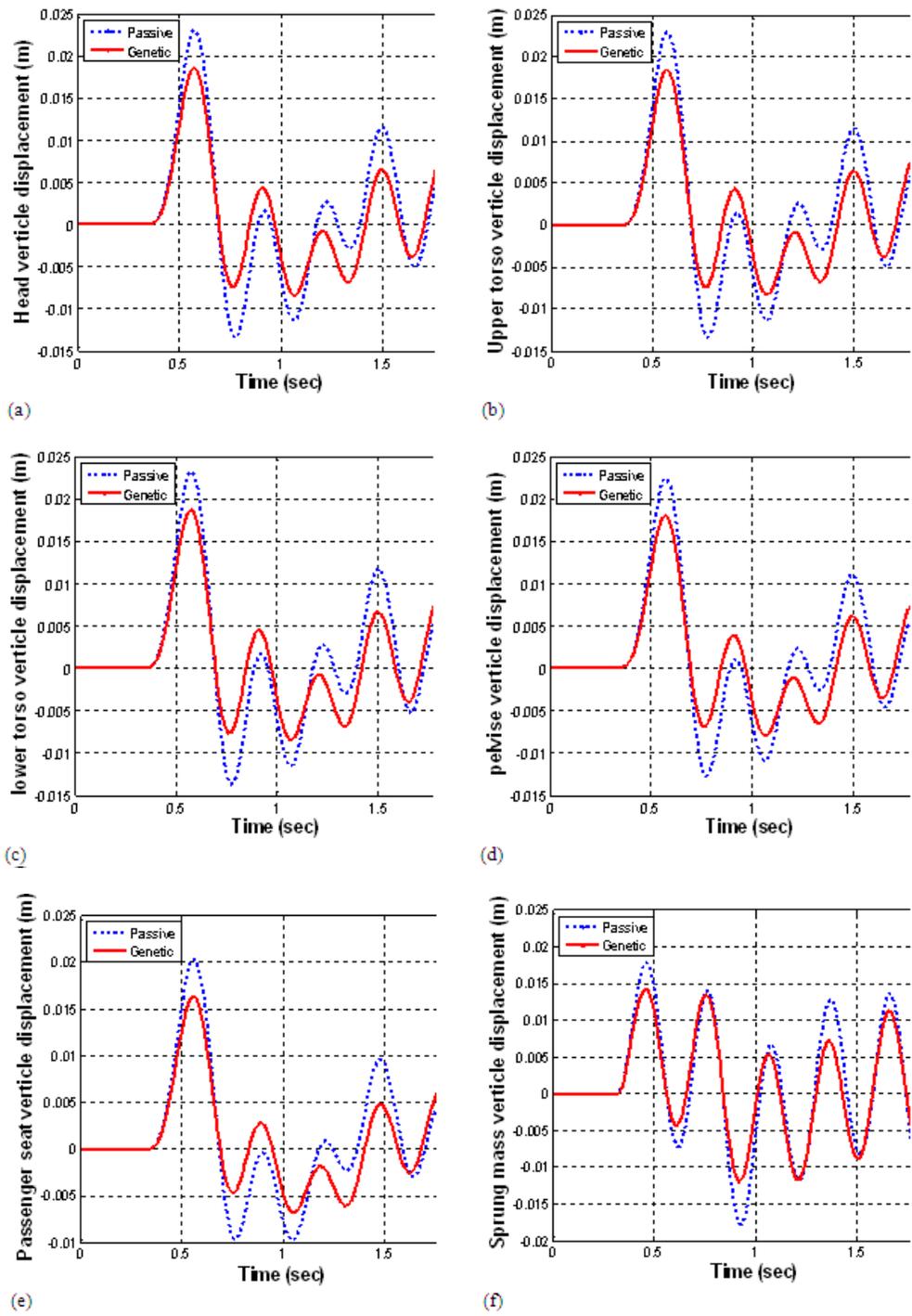
Fig. 5: Sinusoidal displacement histories: (a) head, (b) upper torso, (c) lower torso, (d) pelvic, (e) seat, and (f) sprung mass.
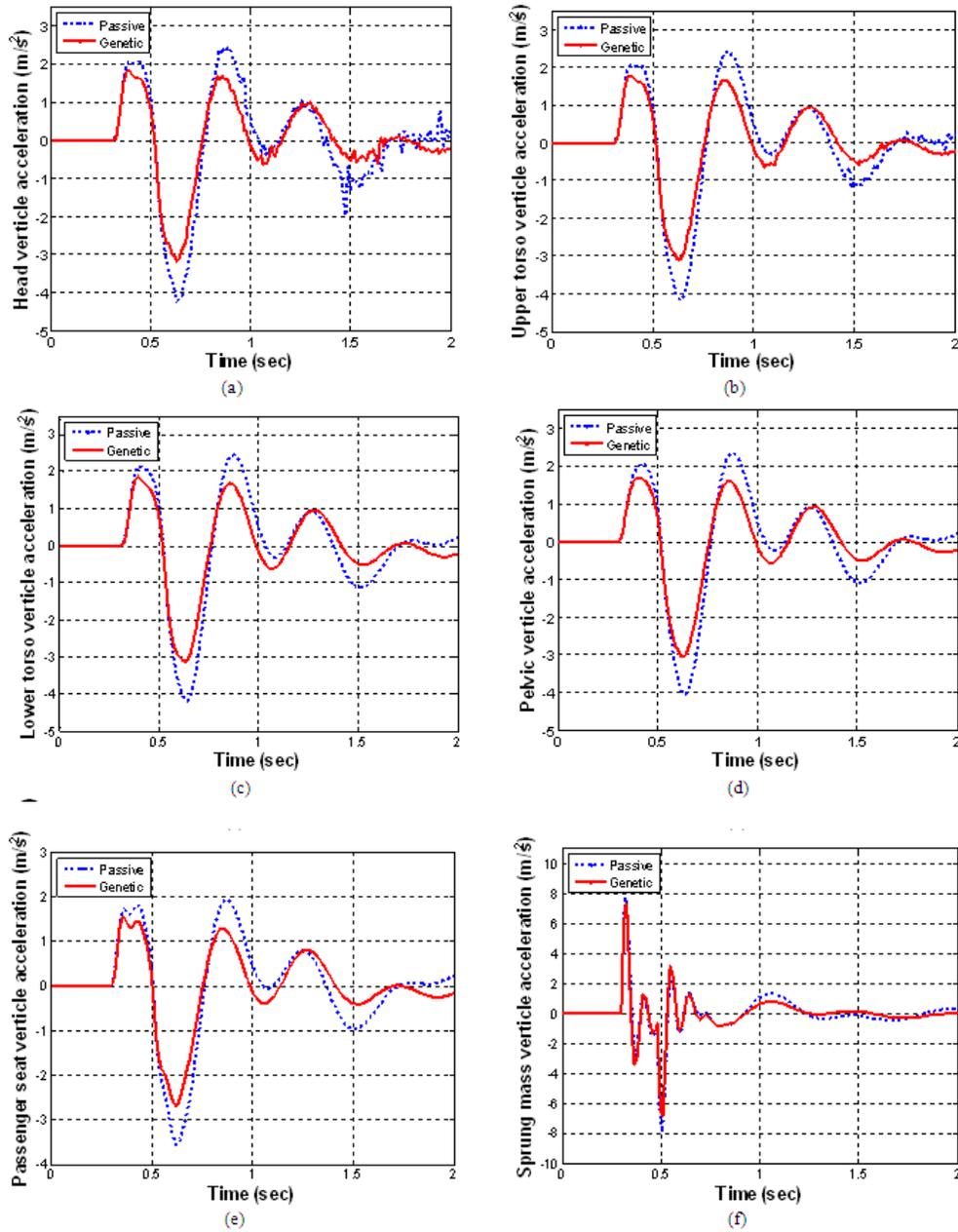
1718

J. Appl. Sci. Res., 7(11): 1709-1720, 2011

Fig. 6: Step acceleration histories: (a) head, (b) upper torso, (c) lower torso, (d) pelvic, (e) seat, and (f) sprung mass.

1719
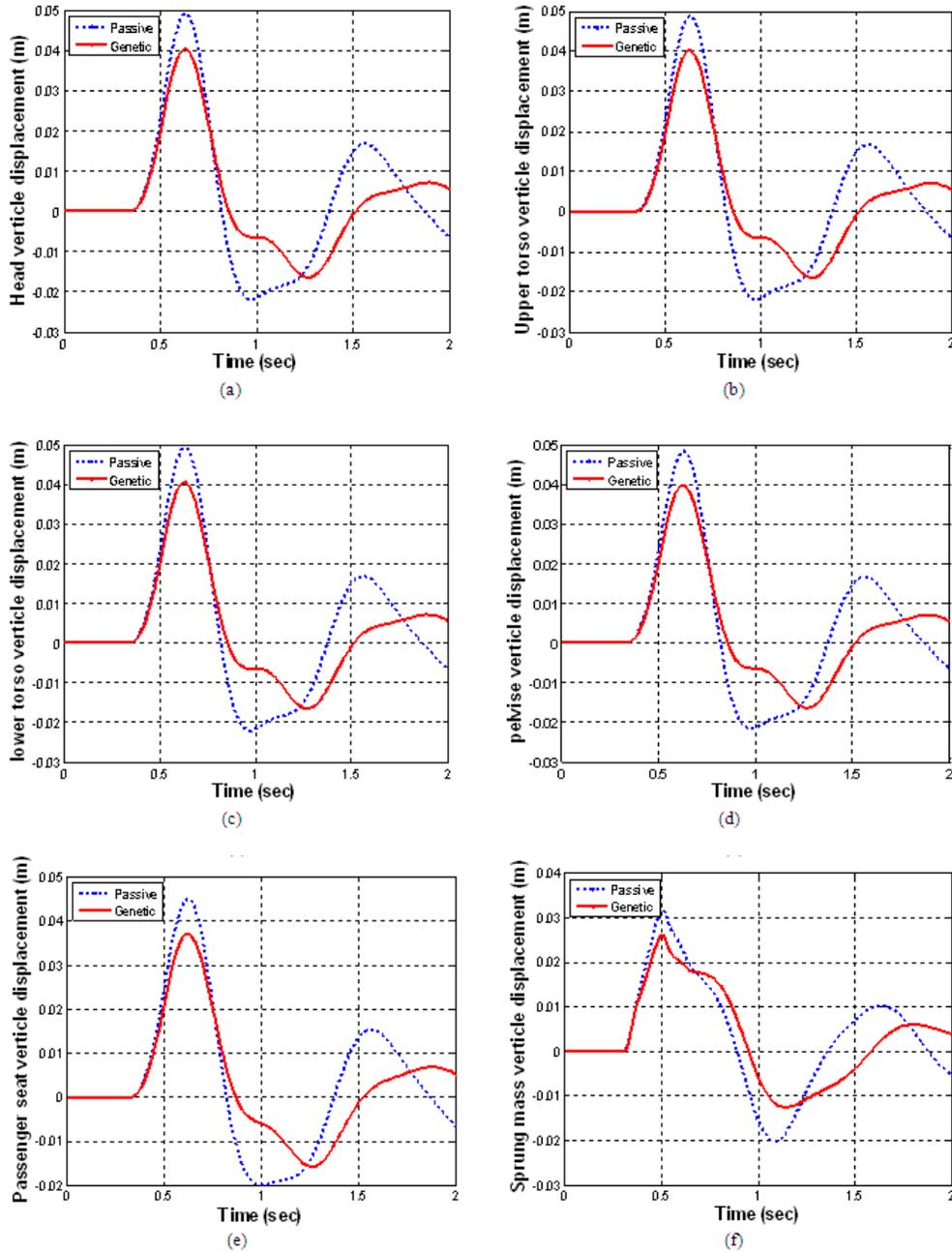
J. Appl. Sci. Res., 7(11): 1709-1720, 2011

Fig. 7: Step displacement histories: (a) head, (b) upper torso, (c) lower torso, (d) pelvic, (e) seat, and (f) sprung mass.

Conclusion:

Both the passive and optimal vehicles suspension systems are compared in time domain analyses subjected to sinusoidal and step input. Passive vehicle systems are the most common because they are cheap and effective for most vibration. The optimal design parameters of the suspension systems obtained are k_s = 10039 N/m and c_s = 900 N.s/m in case of sinusoidal input and k_s = 10030 N/m and c_s = 913 N.s/m in case of step input, respectively. Step excitation input causes more dangerous on whole body parts (Head, upper torso, lower torso, pelvic, seat, and sprung mass) than those produced by sinusoidal excitation input. Human-body acceleration, seat suspension working space, and sprung mass which were reduced by about 21% in case of both sinusoidal and step excitation. The reductions of peak values of are more that 19% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs.

References

Alkhatib, R., G.N. Jazar, M.F. Golnaraghi, 2004. Optimal design of passive linear suspension using genetic algorithm", Journal of Sound and Vibration, 275: 665-691.

Baumal, A.E., J.J. McPhee, P.H. Calamai, 1998. Application of genetic algorithms to the design optimization of an active vehicle suspension system", Computer Methods Appl. Mech. Engrg., 163: 87-94.

Bouazara, M., M.J. Richard, S. Rakheja, 2006. Safety and comfort analysis of a 3-D vehicle model with optimal non-linear active seat suspension", Journal of Terramechanics, 43: 97-118.

Brogioli, M., M. Gobbi, G. Mastinu, M. Pennati, 2011. Parameter Sensitivity Analysis of a Passenger/Seat Model for Ride Comfort Assessment, Experimental Mechanics", DOI: 10.1007/s11340-010-9460-1, Online First™, 22 January

Chen, H., Z.-Y. Liu, P.-Y. Sun, 2005. Application of Constrained H_Control to Active Suspension Systems on Half-Car Models", Journal of Dynamic Systems, Measurement, and Control, 127/353, SEP

Gniady, J., J. Bauman, 1991. Active seat isolation for construction and mining vehicles", SAE Tech. Paper Series,pp. 1–6. Goldberg D.E., Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley Professional, 1 ed., 1989.

Gündoğdu ö. , 2007, Optimal seat and suspension design for a quarter car with driver model using genetic algorithms", International Journal of Industrial Ergonomics, Vol. 37, pp. 327–332.

Hada, M.K., A. Menon, S.Y. Bhave, 2007.Optimisation of an Active Suspension Force Controller Using Genetic Algorithm for Random Input", Defense Science Journal, 57(5): 691-706.

Hassanin, H.S., A.M. Rabeih, S.M. El-Demerdash, K.Y. Younes, 2008. Active Suspension of Highway Truck Seat Using Genetic Algorithms", SAE International, No. -01-1458.

ISO 2631-1:1997. Mechanical vibration and shock Evaluation of human exposure to whole-body vibration -- Part 1: General requirements. International Organization for Standardization.

Liang, C-C., C.-F. Chiang, 2006. A study on biodynamic models of seated human subjects exposed to vertical vibration", International Journal of Industrial Ergonomics, 36: 869-890.

Lu Sun, 2002., Optimum design of "road-friendly" vehicle suspension systems subjected to rough pavement surfaces", Applied Mathematical Modelling, 26: 635-652.

Mehta, C.R., M. Shyam, P. Singh, R.N. Verma, 2000. Ride vibration on tractor-implement system", Applied Ergonomics, 31: 323-328.

Paddan, G.S., M.J. Griffin, 2002. Effect of Seating on Exposures to Whole-Body Vibration in Vehicles, Journal of Sound and Vibration", 253(1): 215-241.

Rakheja, R.G. Dong, S. Patra, P.-É. Boileau, P. Marcotte, C. Warren, 2010. Biodynamics of the human body under whole-body vibration- Synthesis of the reported data", International Journal of Industrial Ergonomics, 40: 710-732.

Schwarze, S., G. Notbohm, H. Dupuis, E. Hartung, 1998. Dose-response relationships between whole-body vibration and lumbar disk disease - a field study of 388 drivers of different vehicles", Journal of Sound and Vibration, 215(4): 613-628.

Stein, G.J., R. Zahoranský, T.P. Gunston, L. Burström, L. Meyer, 2008. Modelling and simulation of a fore-and-aft driver's seat suspension system with road excitation", International Journal of Industrial Ergonomics, 38: 396–409.

Sun, L., X. Cai, J. Yang, 2007. Genetic Algorithm-Based Optimum Vehicle Suspension Design Using Minimum Dynamic Pavement Load as a Design Criterion", Journal of Sound and Vibration, 301: 18-27.

Uys, P.E., P.S. Els, M. Thoresson, 2007. Suspension settings for optimal ride comfort of off-road vehicles travelling on roads with different roughness and speeds", Journal of Terramechanics., 44: 163–175.

Wael Abbas, Ossama B. Abouelatta, Magdy S. El-Azab, Adel A. Megahed, 2010. Application of Genetic Algorithms to the Optimal Design of Vehicle's Driver-Seat Suspension Model", Proceedings of the World Congress on Engineering, Vol. II, June 30 - July 2, 2010, London, U.K., pp: 1630-1635.

Wael Abbas, Ossama B. Abouelatta, Magdy S. El-Azab, Mamdouh El-Saidy, Adel A. Megahed, 2010. Optimization of biodynamic seated human models using genetic algorithms," *SCIRP Journal of Engineering*, 2: 710-719.