Proceedings of the World Congress on Engineering 2010 Vol II
WCE 2010, June 30 - July 2, 2010, London, U.K.

Application of Genetic Algorithms to The Optimal Design of Vehicle's Driver-Seat Suspension Model

W. Abbas, Ossama B. Abouelatta, Magdy S. El-Azab, Adel A. Megahed

***Abstract*—The purpose of a seat suspension system are attempt to isolate vehicle vibration excitations from being transmitted to the drivers and to improve passenger comfort. Traditional seat suspension systems are composed of 2-DOF, that is springs and viscous dampers. This paper, presents a 7-DOF vehicle's driver model with seat suspension system. 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. The optimum design parameters of the suspension systems obtained are k_{se}=5014.1 N/m and c_{se}=55.5 N.s/m in case of sinusoidal input and k_{se}=42934 N/m and c_{se}=50 N.s/m in case of step input, respectively.**

***Index Terms*— Biodynamic response, Genetic algorithms, Seat-driver suspension model, Simulation.**

I. Introduction

In the last fifty years, many people become more concerned about the ride quality of vehicle which is directly related to driver fatigue, discomfort, and safety. As traveling increases, the driver is more exposed to vibration mostly originating from the interaction between the road and vehicle. The vibration experience by the driver is known as whole-body vibration, which occurs when the body is supported on a vibrating surface. Research has shown that operators exposed to low-frequency whole body vibration can experience temporary and even permanent injuries.

In an early studies, various biodynamic models have been developed to depict human motion from single-DOF to multi-DOF models. These models can be divided as distributed (finite element) models, lumped parameter models and multibody models. The distributed model treats the spine as a layered structure of rigid elements, representing the vertebral bodies, and deformable elements representing the intervertebral discs by the finite element method [1]-[2].

Multibody human models are made of several rigid bodies interconnected by pin (two-dimensional) or ball and socket (three-dimensional) joints, and can be further separated into kinetic and kinematic models. The kinetics is interested in the study of forces associated with motion, while kinematics is a study of the description of motion, including considerations of space and time, and are often used in the study of human exercise and injury assessment in a vehicle crash.

The lumped parameter models consider the human body as several rigid bodies and spring-dampers. This type of model is simple to analyze and easy to validate with experiments. However, the disadvantage is the limitation to one-directional analysis. These models can be summarized as: 1-DOF model [3], 2-DOF human body [4], 3-DOF analytical model [5], 4-DOF human model [6]-[8], 6-DOF nonlinear model [9], and 7-DOF model [10]. A complete study on lumped-parameter models for seated human under vertical vibration excitation has been carried out by Liang and Chiang [11], based on an analytical study and experimental validation. So, it is known that the lumped parameter model is probably one of the most popular analytical methods in the study of biodynamic responses of seated human subjects, though it is limited to one-directional analysis. However, vertical vibration exposure of the driver is our main concern.

On the other hand, a genetic algorithms (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. Therefore, genetic algorithms optimization is used to determine both the active control and passive mechanical parameters of a vehicle suspension system and to minimize the extreme acceleration of the passenger's seat, subjected to constraints representing the required road-holding ability and suspension working space [12]-[14].This work presents an optimization of a 7-DOF vehicle's driver with seat suspension system using genetic algorithms to determine a set of parameters to achieve the best comfort of the driver.

II. Mathematical Model

A. Seated-Human Driver Model

This section is devoted to the mathematical modeling of proposed model, including the seat suspension and human body as illustrated in Fig. 1. The human-body, has a 7-DOF that proposed by Patil and Palanichamy [15].The human-body consists of seven mass segments interconnected by eight sets of springs and dampers. The seven masses represent the following body segments: head and neck *(m_1)*, back *(m_2)*, upper torso *(m_3)*, thorax *(m_4)*, diaphragm *(m_5)*, abdomen *(m_6)* and thighs and pelvis *(m_7)*. The arms and legs are combined with the upper torso and thigh, respectively. The stiffness and damping properties of thighs and pelvis are

Manuscript received December 31, 2009.

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ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

k_8 and c_8, abdomen are k_6 and c_6, the diaphragm are k_5 and c_5, the thorax are k_4 and c_4 ,the torso are (k_2, k_3) and (c_2, c_3), back are k_7 and c_7, and head are k_1 and $c1$. The seat suspension system is represented by 1-DOF, consists of seat mass (m_{se}), spring constant(k_{se}) and damping coefficient (c_{se}). The biomechanical parameters of the model are listed in Table 1.

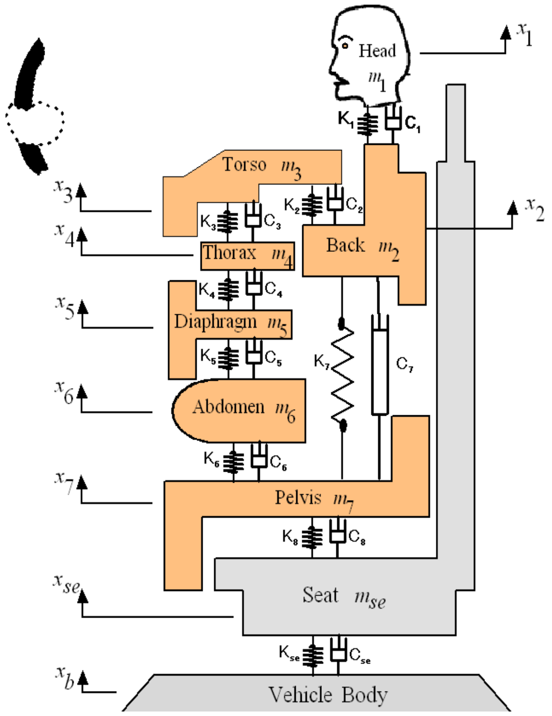

Fig. 1 Schematic diagram of seated-human model.

Table 1 System parameters of the proposed seat suspension and human-body model [10, 16].

Mass (kg)	**Damping coefficient (N.s/m)**	**Spring constant (N/m)**
$m_1 = 5.55$	$C_1 = 3651$	$k_1 = 53640$
$m_2 = 6.94$	$C_2 = 3651$	$k_2 = 53640$
$m_3 = 33.33$	$C_3 = 298$	$k_3 = 8941$
$m_4 = 1.389$	$C_4 = 298$	$k_4 = 8941$
$m_5 = 0.4629$	$C_5 = 298$	$k_5 = 8941$
$m_6 = 6.02$	$C_6 = 298$	$k_6 = 8941$
$m_7 = 27.7$	$C_7 = 3651$	$k_7 = 53640$
	$C_8 = 378$	$k_8 = 25500$
$m_{se} = 15$	$C_{se} = 2156$	$k_{se} = 19600$

Therefore, the governing equation of motion of the seat suspension can be obtained as follows:

$$m_{se}\ddot{x}_{se} = -k_{se}(x_{se} - x_b) - c_{se}(\dot{x}_{se} - \dot{x}_b) + k_8(x_7 - x_{se}) + c_8(\dot{x}_7 - \dot{x}_{se}) \quad (1)$$

A mathematical model of the human-body can be obtained as follows:

$$m_7\ddot{x}_7 = k_6(x_6 - x_7) + c_6(\dot{x}_6 - \dot{x}_7) + k_7(x_2 - x_7) + c_7(\dot{x}_2 - \dot{x}_7) - k_8(x_7 - x_{se}) - c_8(\dot{x}_7 - \dot{x}_{se}) \quad (2)$$

$$m_6\ddot{x}_6 = k_5(x_5 - x_6) + c_5(\dot{x}_5 - \dot{x}_6) - k_6(x_6 - x_7) - c_6(\dot{x}_6 - \dot{x}_7) \quad (3)$$

$$m_5\ddot{x}_5 = k_4(x_4 - x_5) + c_4(\dot{x}_4 - \dot{x}_5) - k_5(x_5 - x_6) - c_5(\dot{x}_5 - \dot{x}_6) \quad (4)$$

$$m_4\ddot{x}_4 = k_3(x_3 - x_4) + c_3(\dot{x}_3 - \dot{x}_4) - k_4(x_4 - x_5) - c_4(\dot{x}_4 - \dot{x}_5) \quad (5)$$

$$m_3\ddot{x}_3 = -k_2(x_3 - x_2) - c_2(\dot{x}_3 - \dot{x}_2) - k_3(x_3 - x_4) - c_3(\dot{x}_3 - \dot{x}_4) \quad (6)$$

$$m_2\ddot{x}_2 = k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2) + k_2(x_3 - x_2) + c_2(\dot{x}_3 - \dot{x}_2) - k_7(x_2 - x_7) - c_7(\dot{x}_2 - \dot{x}_7) \quad (7)$$

$$m_1\ddot{x}_1 = -k_1(x_1 - x_2) - c_1(\dot{x}_1 - \dot{x}_2) \quad (8)$$

B. *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, $x_b = Asin(\omega t)$ where, $\omega = \frac{\pi V_c}{D}$,, and A (0.025 m) is the hump height. D (0.8 m) is the width of the hump, and vc is the vehicle velocity. This excitation assumed that the vehicle model travels with a constant velocity of 23 km⁄h (6.38 m⁄s). The second types of road is step profile. The step height was 0.02 m applied instantaneously.

III. Numerical Simulations Model

The seat-driver model was simulated using MATLAB software ver. 7.8 (R2009a) dynamic system simulation software, Simulink. A Simulink model was constructed by using the differential equations derived by applying Newton's law to the seat-driver model.

IV. Genetic Algorithms

Genetic algorithms (GAs) are stochastic techniques whose search methods model a natural evolution. These algorithms are based on Darwin's theory of 'survival of fittest' [17, 18]. This means that problems are solved by an evolutionary process which is used to optimize the solutions to a given problem (the solution is not always the best). GA uses a probabilistic process to find approximate solutions to difficult to solve problems through application of the principles of evolutionary biology to computer science.

A. *Genetic Algorithm Techniques*

Genetic algorithms are typically implemented as a computer simulation in which a population of abstract representations (called chromosomes) of candidate solutions to an optimization problem (called individuals) taken from a search space evolves toward better solutions. The evolution starts from a population of completely random individuals and takes place in several generations. In each generation, multiple individuals are stochastically selected from the current population, modified (mutated or recombined) to form a new population, which becomes the current population in the next iteration of the algorithm. A measure of how good a solution is to solve the problem, called fitness function, is also necessary in the evolutionary process. A simple genetic algorithm that yields good results in any practical problem is composed of following three operations [14]:

Reproduction: A process in which individual strings are copied according to their objective function values.

Crossover: Here, pairs of strings are picked at random from the existing population to be subjected to crossover.

Mutation: After crossover, strings are subjected to mutation. Mutation is applied to each child individually. The flow chart of the optimization procedure used in the research calculations is shown in Fig. 2.

For the optimization using genetic software, one must choose:

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

1. the objective function or the performance index which is required to be minimized.
2. the bounds of the design variables which are limited to lower and upper bounds, (LB, UB). Within these limits the genetic algorithm choose the values of the design variables during the simulation.
3. the number of individuals which are produced in each generation.
4. the maximum number of generation.
5. the generation gap.
6. the precision of the binary representation.
7. the accuracy.

The program will terminate when the accuracy reach to the setting value or when the maximum generation is reached. Table 2 shows the GA parameters and its selected values.

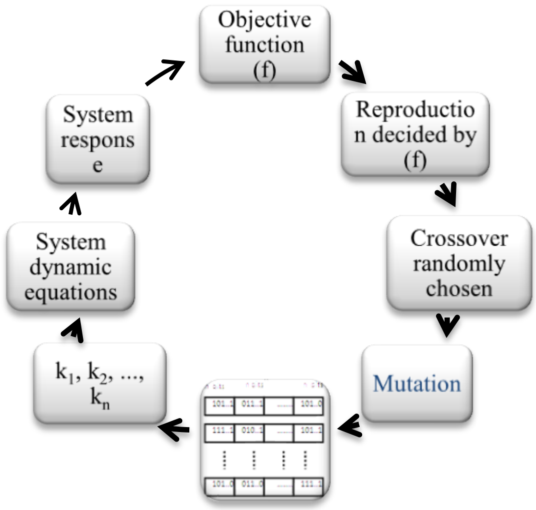

Fig.2 Flowchart of the optimization procedure.

Table 2 Genetic algorithm parameters.

GAparameters	value
Population size	50
No of generations	100
Fitness scaling	Rank
Crossover technique	Heuristic
Probability of crossover	0.8
Mutation technique	Uniform
Generation gap	0.9
Lower boundary	50-50000
Upper boundary	1000-300000
Objective function accuracy	$1e^{-15}$

B. *Objective Function*

Head acceleration, force transmitted to the upper body, and the seat suspension working space (seat suspension deflection) are the most important factors affecting driver's health and comfort [19]. Therefore, the objective function of this study combines head acceleration ($\ddot{\boldsymbol{x}}_{\mathbf{1}}$), seat mass acceleration ($\ddot{\boldsymbol{x}}_{se}$), and the seat suspension working space (ssws) to achieve the best comfort of the driver.

This study used the classical weighted sum approaches to solve a multi-objective optimization problem as follows [20]:

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

where w1, w2 and w3 are weighting factors to emphasize the relative importance of the terms. Table 3, shows weighting factors used in step and sinusoidal excitation inputs.

Table 3 Weighting factors used in step and sinusoidal excitation inputs.

Weight	w_1	w_2	W_3
Step Input	1.5	1.0	1.1
Sinusoidal input	1.5	1.0	1.1

V. 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 seat 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 4. Simulation is performed using seat-driver data illustrated in table 1, for the defined seat excitation inputs.

Table 4The design results from the GA program for passive and optimal suspension.

Seat suspension setting	Currently used	GA optimization	
		Sinusoidal	Step
K_{se}	19600	5014.1	42934
C_{se}	2156	55.5	50

Figs.3 and 4 present the history of the some selected response components of the human-body model for sinusoidal input excitation. In particular the results in Fig.3, depict the acceleration histories obtained at the seven human components, head and neck, back, upper torso, thorax, diaphragm, abdomen and thighs and pelvis, respectively. The maximum amplitude of acceleration determined in all seven human components is increased originally and then decreased. Whereas, Fig.4 shows the displacement histories obtained at the seven human components.

On the other hand, Figs. 5 and 6 present the same part of the history determined response components for the human-body model, in case of step input excitation. In addition, Fig. 7 presents seat suspension working space obtained at sinusoidal input excitation and step input excitation. Therefore, in order to verify the validity of the results, the GA were compared to those obtained by passive suspension for head, chest, lumber and pelvic of the human body using two different excitation input: sinusoidal and step inputs.

The results of Figs.3-7 and table 5 indicate that the reduction of the driver's vertical acceleration is approximately 78 % and 50–91% in case of GA suspension as compared with passive suspension for sinusoidal and step excitation inputs, respectively. The reduction of the driver's vertical displacement peak is approximately 51 % and 31 % 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 approximately 78 % and 44 % in case of GA suspension as compared withpassive suspension for sinusoidal and step excitation inputs, respectively.

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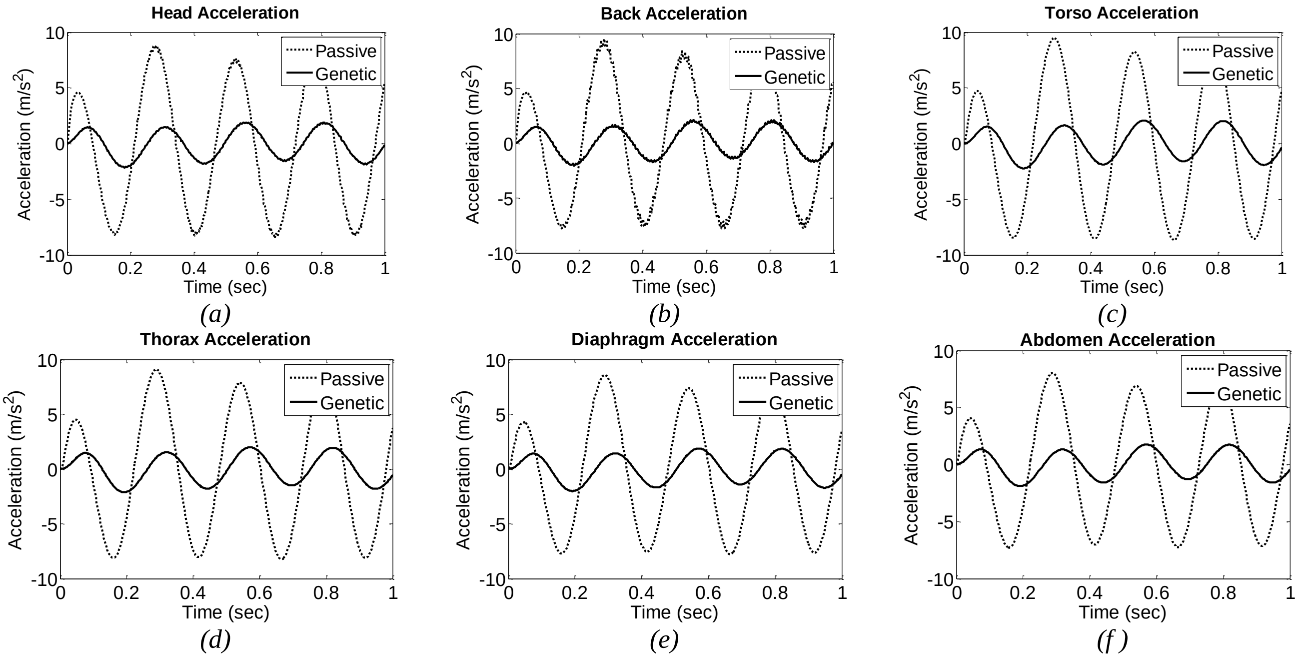


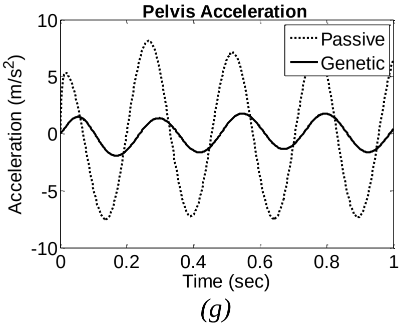
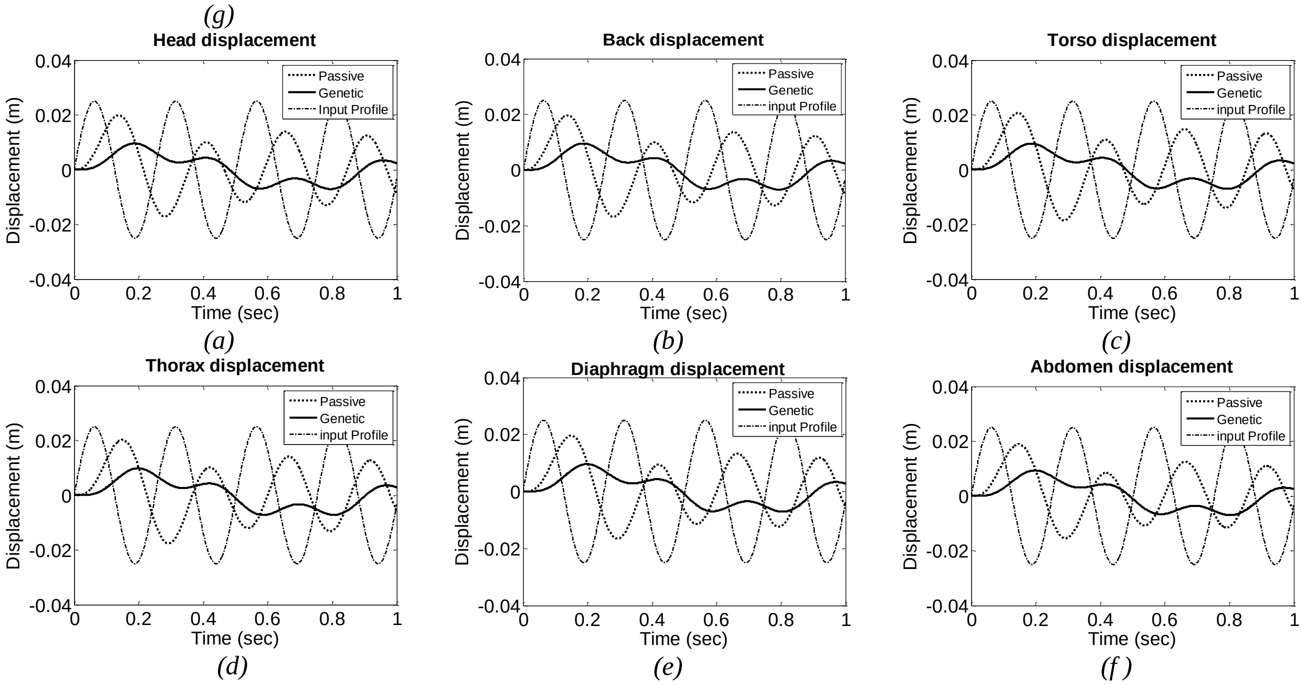


Fig.3 Acceleration histories obtained at (a) Head, (b) Back, (c) Torso, (d) Thorax, (e) Diaphragm, (f) Abdomen and (g) Pelvic using a sinusoidal input excitation.



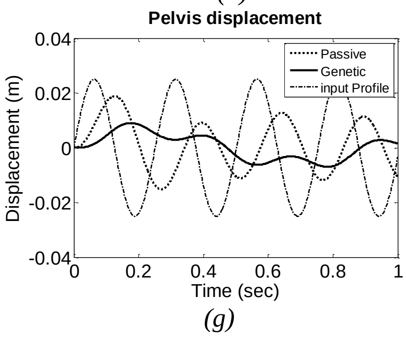


Fig.4 Displacement histories obtained at (a) Head, (b) Back, (c) Torso, (d) Thorax, (e) Diaphragm, (f) Abdomen, (g) Pelvic and (h) Seat suspension working space using a sinusoidal input excitation.

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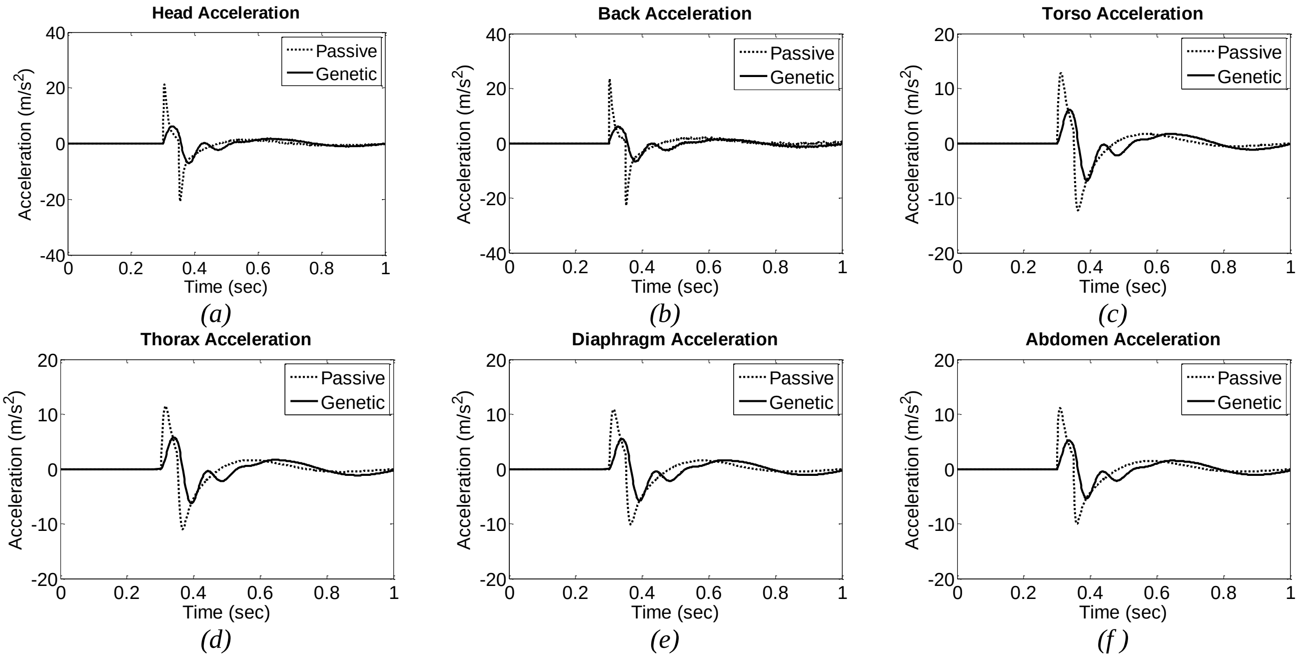
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



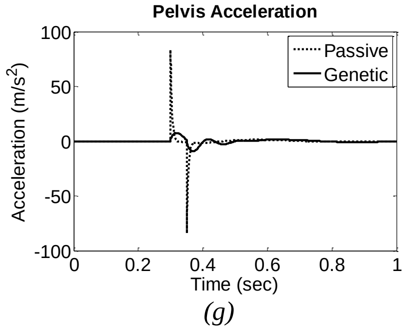
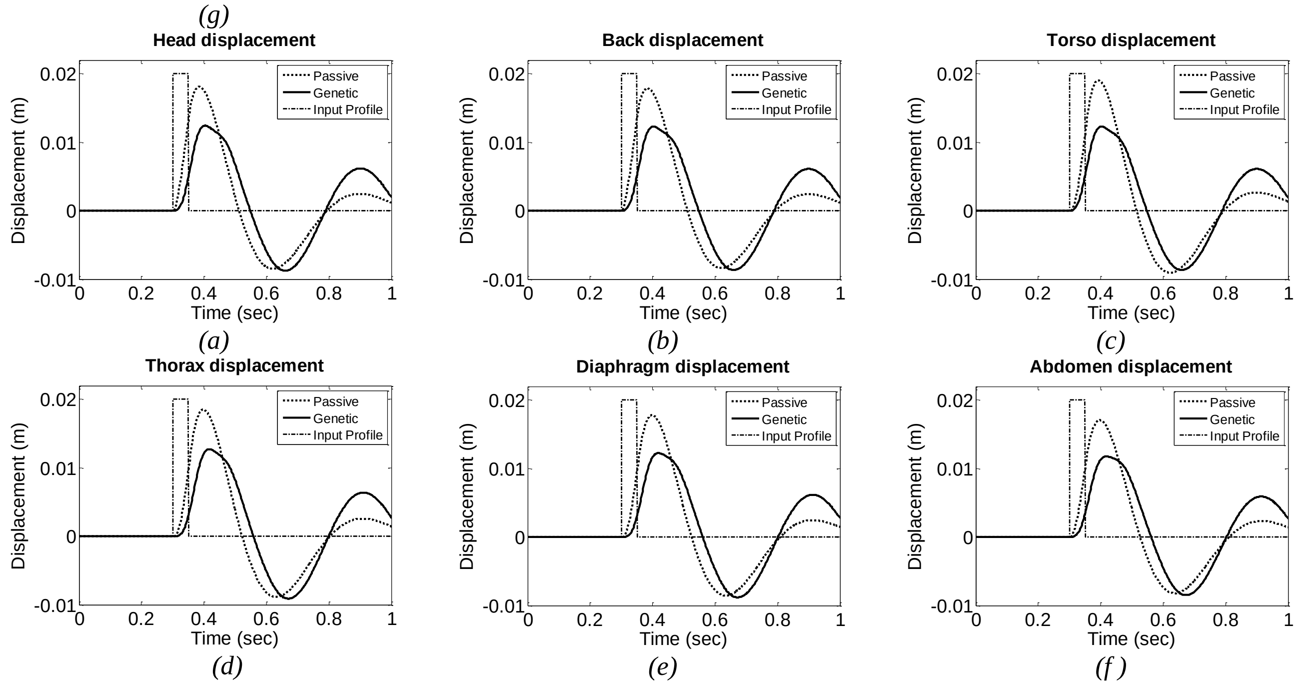


Fig.5 Acceleration histories obtained at (a) Head, (b) Back, (c) Torso, (d) Thorax, (e) Diaphragm, (f) Abdomen and (g) Pelvic using a step input excitation.



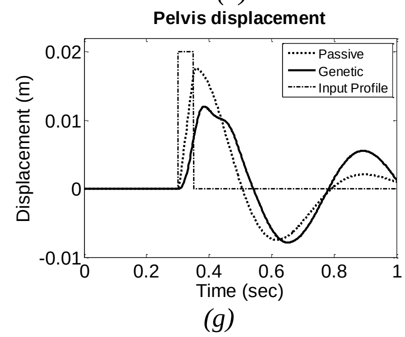


Fig.6 Displacement histories obtained at (a) Head, (b) Back, (c) Torso, (d) Thorax, (e) Diaphragm, (f) Abdomen, (g) Pelvic and (h) Seat suspension working space using a step input excitation.

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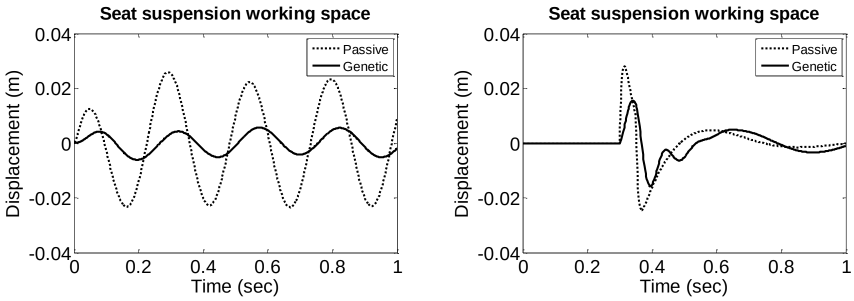

(a) (b)

Fig.7 Seat suspension working space obtained at (a) sinusoidal and (b) step input excitation.

Table 6 Comparison of passive and GA results for driver's body parts.

Driver's Body		Sinusoidal		Red.%	Step		Red.%
		Max. overshoot		Peak overshoot	Max. overshoot		Peak overshoot
		Passive	GA		Passive	GA	
Acceleration (m/s^2)	Head	8.7921	1.9141	78.23	21.3459	6.2190	70.86
	Back	9.5130	2.1174	77.74	23.5776	6.0797	74.21
	Torso	9.4904	2.0662	78.22	12.7415	6.0749	52.32
	Thorax	9.0757	1.9775	78.21	11.5122	5.7464	50.08
	Diaphragm	8.5633	1.8685	78.18	10.8672	5.4393	50.00
	Abdomen	8.0331	1.7533	78.17	11.1764	5.1767	53.68
	Pelvis	8.1329	1.7729	78.20	83.6045	7.4989	91.03
Displacement (m)	Head	0.0198	0.0096	51.51	0.0181	0.0124	31.50
	Back	0.0196	0.0095	51.53	0.0179	0.0123	31.28
	Torso	0.0207	0.0100	51.69	0.0190	0.0131	31.05
	Thorax	0.0202	0.0098	51.48	0.0185	0.0127	31.35
	Diaphragm	0.0196	0.0096	51.02	0.0178	0.0123	30.89
	Abdomen	0.0189	0.0093	50.79	0.0171	0.0118	30.99
	Pelvis	0.0188	0.0090	52.12	0.0176	0.0120	31.81
SSWS		0.0259	0.0056	78.37	0.0280	0.0155	44.64

VI. CONCLUSIONS

A 7-DOF passive and optimal seat driver suspension systems are compared in time domain analyses subjected to sinusoidal and step inputexcitation. The optimum design parameters of the suspension systems obtained are k_{se}=5014.1 N/m and c_{se}=55.5 N.s/m in case of sinusoidal input and k_{se}=42934 N/mandc_{se}=50N.s/m in case of step input, respectively. The Head acceleration was reduced by more than 70 % and for head displacement was reduced by more than 31.5%. The reduction of peak over shoot of seat suspension working space (ssws) about 78 % in case of sinusoidal input and 44 % in case of step input.

It is obvious from the results and plot indicate that optimal seat suspension system are less oscillatory, and have lower values of maximum over shoots , which is directly related to driver fatigue, discomfort, and safety. Therefore, optimal seat suspension system has better potential to improve driver comfort.

Step excitation input causes more dangerous on whole body parts (head and neck, back, upper torso, thorax, diaphragm, abdomen and thighs and pelvis) than those produced by sinusoidal excitation input.

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