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Optimization, development and evaluation of a tractor seat suspension via artificial intelligent method

Mohammad Gohari [a], **Mona Tahmasebi** [b], **Farzad Rafieian** [a,*], **Abbas Pak** [c]

[a] *Faculty of Mechanical Engineering, Arak University of Technology, Arak, IRAN*

[b] *Agricultural Engineering Research Department, Markazi Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Arak, IRAN*

[c] *Faculty of Mechanical Engineering, Engineering School, Bu-Ali Sina University, Hamedan, IRAN*

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ABSTRACT

Tractor drivers' health is very important and injuries can develop in the long run such as back pain or spinal column disorder resulting from low-frequency vibrations. Seat suspension plays a crucial role in the reduction of harmful vibrations in off-road vehicles. Passive suspension design parameters should be tuned properly to remove vibrations efficiently. Lumped parameter models have been widely used in seat suspension optimization to simulate human body responses. In this study, a tractor seat suspension is designed based on an artificial neural network biodynamic model instead of a lumped model. For optimization, a novel approximation approach via an artificial neural network is employed to minimize seat-to-spine vibrations transmissibility. Then, seat suspension is modified based on optimization results and outdoor dynamic test is carried out to evaluate transmissibility attenuation. Data were analyzed in terms of vibration transmissibility, mobility and apparent mass. Transmitted vibration ratio from floor to spine was measured between 0.2 to 0.4 at 4-6 Hz (spine dominant frequency range) on bumpy and smooth roads at various traveling speeds. Seat suspension modification is shown effective on vibration transmissibility performance. Thus, this passive suspension may decrease the risk of lower back pain for tractor drivers. This modification can be considered by tractor manufacturers for future models of better comfort for operators.

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[*] Corresponding author.
E-mail addresses: moh-gohari@arakut.ac.ir (M. Gohari), Tahmasebi.mona@gmail.com (M. Tahmasebi), farzad.rafieian@gmail.com (F. Rafieian), a.pak@basu.ac.ir (A. Pak).

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1. Introduction

Low back pain (LBP) is one of the adverse effects of exposing low-frequency vibration in the long term [1-3]. Not only are vehicle suspensions essential, but seat suspensions also have an effective influence on removing unwanted vibrations. In low-speed and heavy-duty vehicles such as construction machines and agriculture tractors without suspension, the role of seat suspension is intensified. Normally, passive seat suspension systems in off-road vehicles consist of viscous dampers and springs with low stiffness to diminish vibration amplitude in the critical vibration range for human body resonance (4-8 Hz).

Lumped models are usually used to study and predict human bodies' response to vibration. Lumped models consist of springs, dampers and masses to simulate human body reactions to dynamic motions. The earliest research in this area was done by [4] who established a one degree of freedom (1DOF) dynamic model for this purpose. After this model, other models were introduced with more degrees of freedom. 2DOF models were represented by [5-7]. In these models, in addition to body, head vibration was also considered. In the study by [8], authors separated upper torso and lower torso motion; therefore, their model is a 3DOF dynamic model. Also in another study by [9], researchers optimized a seat suspension design to develop a 4DOF model. They isolated vibration transmitted to the body by simulating subjective responses. Similar to Wan-Schimmels model, [10] and [11] unveiled 4DOF models which considered viscera.

The tractor seat suspension system was optimized via a 7DOF nonlinear model by [12]. Their model includes many segments like the pelvis, abdomen, diaphragm, thorax, torso, back and the head. Furthermore, an innovative system has been developed to reduce vibrations on agricultural tractors [13]. Moreover, the interaction of soil-tyre in tractor and transmitted vibration was modelled by lumped model [14]. In addition, multi body dynamic models were employed to optimize the performance of tractor suspension [15, 16]. Recently, artificial intelligence methods have been employed in vibration modelling and prediction [17-19]. This method has good potential for multi-parameter modelling and optimization. In most investigations on seat suspension optimization, the focus has been only on seat parameters while human body reaction to vibration was not considered. In controlling vibration transmissibility by designing seat suspension, the reaction of human body parts like the spine must be considered and minimized. Thus, via an accurate and smart model, the transmitted vibration can be reduced through an optimization method properly tuned by evolution or empirical techniques. In this paper, using the artificial neural network and a human body model from experimental data gathered by proper accuracy, the passive seat suspension is optimized and evaluated through an ANN optimization method as an empirical model.

2. Material and methods

2.1 Development of ANN for optimization

As most research has been focusing on seat suspension characteristics and tractor dynamics, the lack of consideration on the study of human body biodynamics in suspension design is evident. For this purpose, an artificial neural network biodynamic model (ANNBM) was employed to represent the response of the spine to the vertical vibration from excitation acceleration at the pelvis [20]. The ANNBM can predict the output signal from three inputs: human weight, height and seat acceleration signal. The accuracy of ANNBM in time is 94.85 percent. Thus, this biodynamic model simulates driver spine vibration, and seat suspension can be tuned to minimize spine movement. The main aim of this optimization is to decrease the seat-to-spine vibration transmissibility (SST) to reduce the risk of lower back pain at the dominant spine natural frequency (4-6 Hz).

To formulate this problem and find a feasible solution, a relationship between the two first peaks of SST and seat suspension design factors such as spring constant, damper coefficient and seat mass must be constructed. Consequently, ANN has been utilized to play the role in this relationship. Equation (1) illustrates this association:

$$SST(P_1, P_2) = f_{ANN}(m, C, K) \tag{1}$$

Where P_1 and P_2 are SST peak values, and m, C, K are seat mass, damper coefficient, and spring constant, respectively. On the other hand, the inverse of this function can be stated as Equation (2):

$$(m, C, K) = f^{-1}{}_{ANN}(P_1, P_2) \tag{2}$$

If this ANN is trained correctly and the relationship between variables is derived, ANN can estimate optimal m, C and K which result in minimum values for P_1 and P_2. The SST peaks must be lower than 1 to remove undesirable vibration by suspension.

Given ANN requires some examples for training, seat suspension with various triple factors (m, C and K) was simulated with Working Model 2D software to provide training data. As depicted in Fig. 1, seat suspension was exposed to harmonic vibration via an eccentric rotary circle. This configuration was constrained to vibrate in the vertical direction. Vertical acceleration at the seat was recorded and passed to ANNBM. Finally, ANNBM predicted spine acceleration. The frequency of vibration was 4Hz due to the first natural frequency of spine, and the amplitude of harmonic vibration was 5 mm concerning the assumptions by [10]. The revolution speed is 10 rad/s. So, the equation of seat vibration is:

$$\ddot{Z}_0 = 5\omega^2 sin\omega t \tag{3}$$

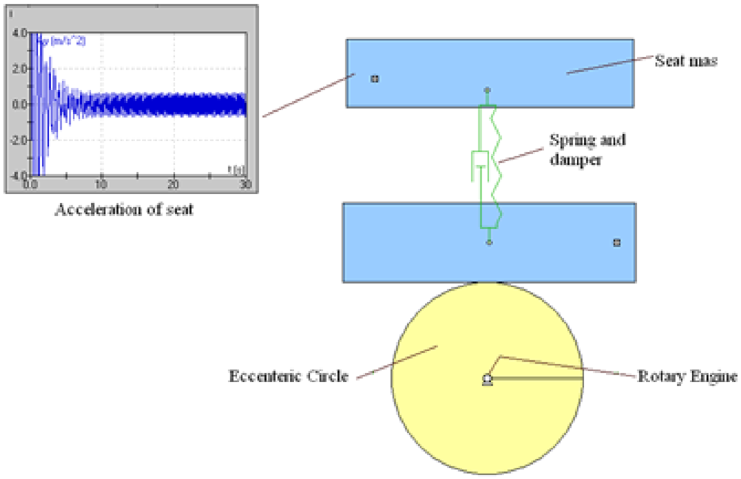

Fig. 1: Seat dynamic simulation in 2D Working Model software

Eight examples have been made by this method, and seat-to-spine vibration was obtained by Equation (4):

$$SST = \frac{a_{Spine}}{a_{Seat}} \tag{4}$$

Where a_{Spine} and a_{Seat} are output acceleration at spine and seat as excitation signals respectively. The Fast Fourier Transformation (FFT) was used to convert time domain data to frequency domain according to equation 5:

$$a(k) = \sum_{n=0}^{N-1} a(n) e^{-j2\pi kn/N} \qquad \text{for} \qquad k=0, 1, 2, \ldots, N-1 \tag{5}$$

Where $a(k)$ is acceleration in frequency domain. Table 1 exemplifies eight examples achieved by ANNBM.

Table 1. The seat properties in 8 examples and SST peaks

Example No.	m (kg)	C (N.s/m)	K (N/m)	Amplitude of first peak in SST	Amplitude of second peak in SST
1	15	125	8100	0.081	0.07
2	13	120	8150	0.082	0.063
3	15	130	8150	0.084	0.061
4	14	128	8100	0.08	0.058
5	16	120	8200	0.081	0.06
6	13	130	8000	0.08	0.06
7	13	100	8100	0.082	0.059
8	14	125	8130	0.07	0.06

This process is shown by a flowchart in Fig. 2. The first step is obtaining seat acceleration by software simulation, and the second step is feeding ANNBM by seat acceleration and getting spine vibration. Through the final step, optimal peaks of SST are entered in ANN to reach m, C and K.

2.2 ANN topology

A feed-forward with back propagation neural network was selected for optimization. The network was trained and adapted with eight examples. After training and adapting, the correlation ratio of regression between actual examples and model output was reached. Finally, the network was simulated to have minimum first and second SST as 0.06 and 0.04. As a result of this simulation, optimal values of seat mass, spring constant and damper coefficient can be found.

The correlation ratio between input and target values in the 5-layers artificial neural network model was 0.9655. The simulation result by this network for having minimum first and second SST shows

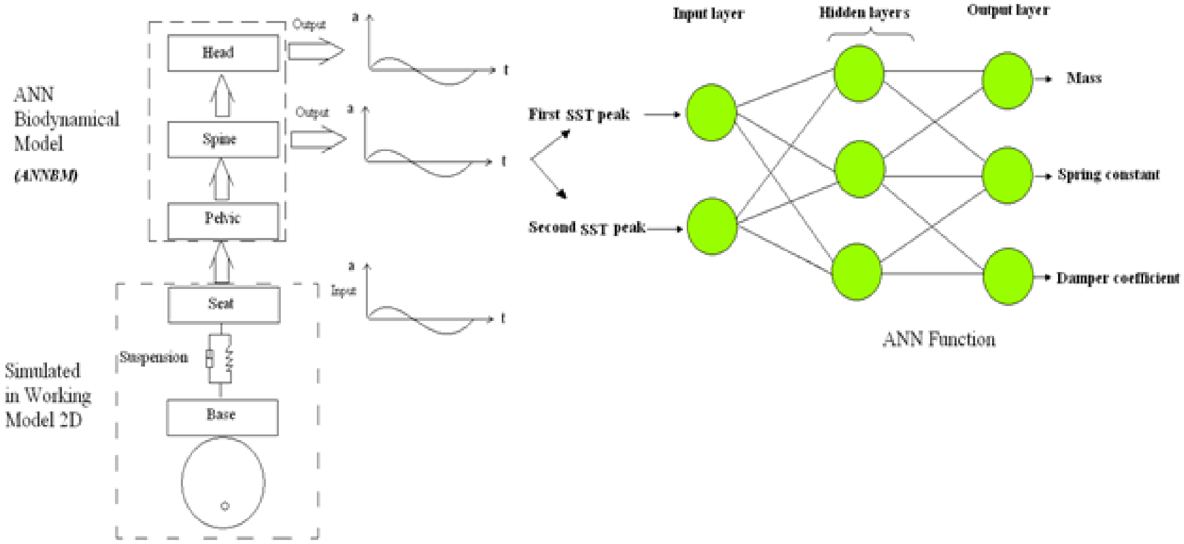

Fig. 2: The output of ANNBM connected to ANN function

16 kg, 8000 N/m and 130N.s/m for seat mass, spring and damper, respectively. These parameters were adjusted in seat suspension to evaluate the efficiency of the road trail.

2.3 Modification of seat suspension based on optimization

A tractor seat suspension belonging to ITMCO285 was modified based on ISO 4253 (1993) for agricultural tractors and optimal values were calculated by the optimization process. Table 2 illustrates the standard dimension of the seat referring to ISO 4253 (1993).

Table 2. Seat dimension referred to ISO 4253

Dimensions	ISO4253 (1993)	Fabricated seat
Seat pan width (mm)	>450	500
Seat length (mm)	210-310	400
Seat pan tilt (°)	3-12	10
Seat backrest width (mm)	-	500
Seat backrest height (mm)	>260	500
Seat backrest inclination (°)	95-105	100
Seat height (mm)	-	Base:600

The coil springs and viscous shock absorbers were replaced on the seat frame based on improved values. Figure 3 demonstrates the improved seat suspension. Evaluation of this changed passive

Fig. 3: Improved seat suspension (Damper Coefficient=130 N.s/m, Spring constant=8000 N/m, Mass=16

seat suspension was carried out by outdoor dynamic test (road test) to determine the efficiency of suspension in removing low-frequency vibration to which the spine is exposed.

2.4 Outdoor dynamic tests

Road tests have been carried out by identifying vibration transmissibility from seat-to-spine to corroborate the efficiency of improved seat suspension. The modified seat structure was mounted on the tractor, and five healthy male passengers were selected to experience random vibration generated by road roughness (ISO 1985). The forward velocities of the vehicle were set to 10 km/h, 20 km/h and 30 km/h, and two types of paths were chosen in this road trail: smooth and bumpy. To determine human bodies' responses to vertical vibration, three accelerometers were employed.

Fig. 4: ITMCO285 used in the road test

The first one was attached to the seat stand on the bottom, and the second one was installed to the human subject spine. The last transducer was situated on the head via the helmet. Figures 4 and 5 illustrate the tractor used in the test and data logger, which is recording vibration. A transportable data logger shown in Fig. 6, was used to record data via Dewesoft 6.2 software. The vibration sensor is ADXL 335. After data gathering, the seat-to-spine vibration transmissibility (SST) was computed in the frequency domain by means of MATLAB software.

Fig. 5: Five-channel transportable data acquisition system

3. Results and discussion

As mentioned earlier, the natural frequency range of the spine is between 4 Hz to 6 Hz, and the major goal of seat suspension enhancement was diminishing SST to lower than 1 in this range.

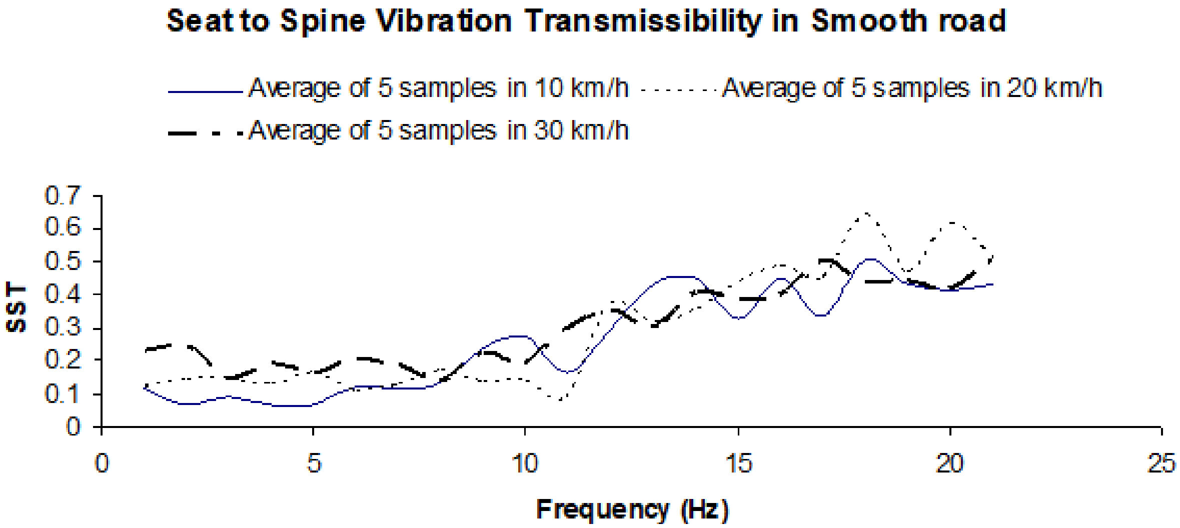

Fig. 6: Average of SST for smooth road for three forward velocities

The graphs in Fig. 6 and 7 show the average SST for five samples at smooth and bumpy roads at three forward speeds. As depicted in these figures, the SST is lower than one in various forward velocities between 4 to 6 Hz.

The average results of five samples, Fig. 6, demonstrate that the SSTs in the purposed range of spine natural frequencies are lower than 0.3. Additionally, in a frequency range lower than 10 Hz, by rising forward velocity from 10 to 30 km/h, the SST has increased while after this point, higher forward velocity leads to a decrease in SST. Increased ride vibration damages comfort and activities [21].

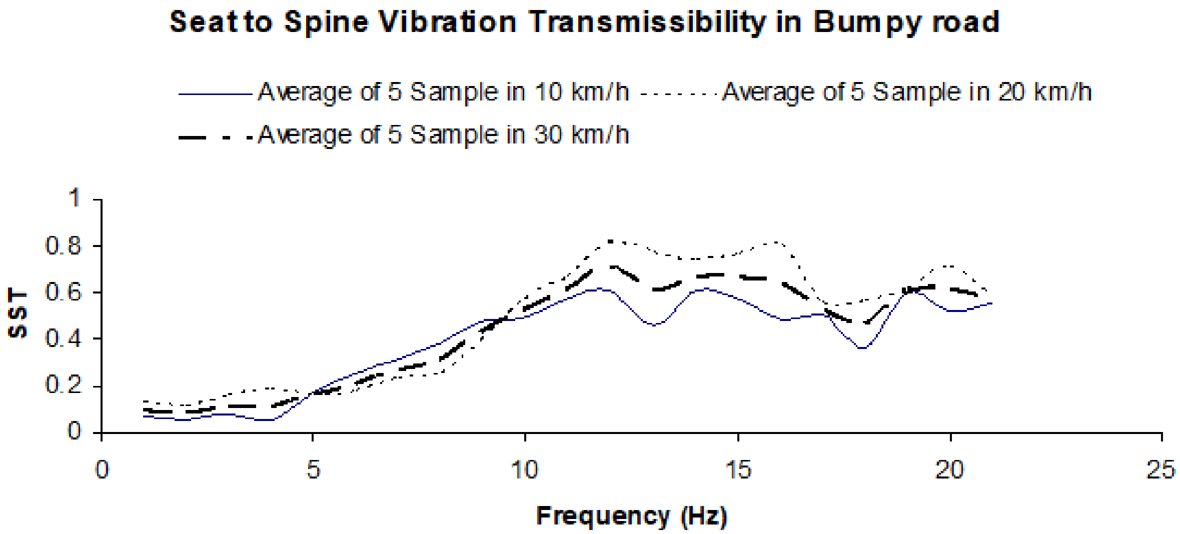

Fig. 7: Average of SST for bumpy road for three forward speeds

From Fig. 7, it can be found that the average SST on a bumpy road affirms that the value of SST is lower than 0.2 in the spine natural frequencies range (4 Hz to 6 Hz), and it was increased by forward velocity rising.

Moreover, the comparisons between bumpy road and smooth road in three forward velocities are shown in Fig. 8 to Fig. 10. As can be viewed in these figures, after 5 Hz, SST on the bumpy road for all the forward speed is extremely higher than the smooth road, but there is no rational variety lower this frequency. In range of 4 to 6 Hz, the SST in bumpy road is lower than smooth road. That might be due to the fact that in low-speed, human passenger feels comfort in smooth road, and vibration transmissibility is little bit higher than bumpy road. In fact, he or she release their muscles.

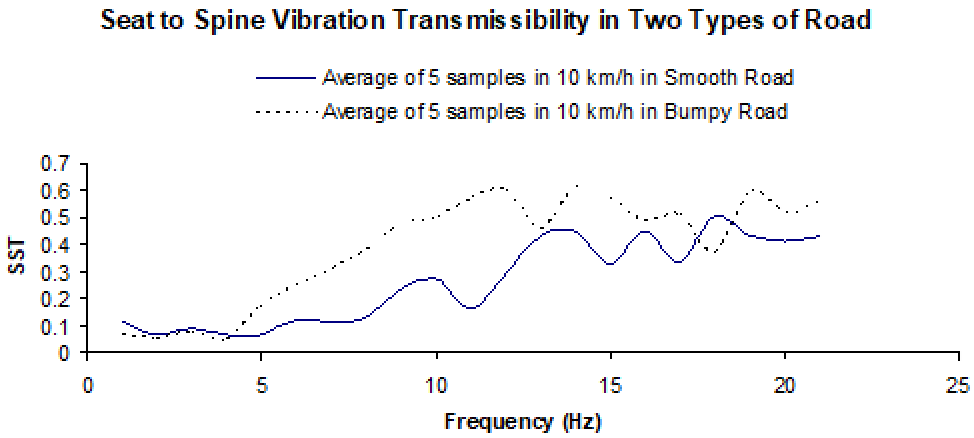

Fig. 8: Comparison between SST in smooth road and bumpy road, 10 km/h forward velocity

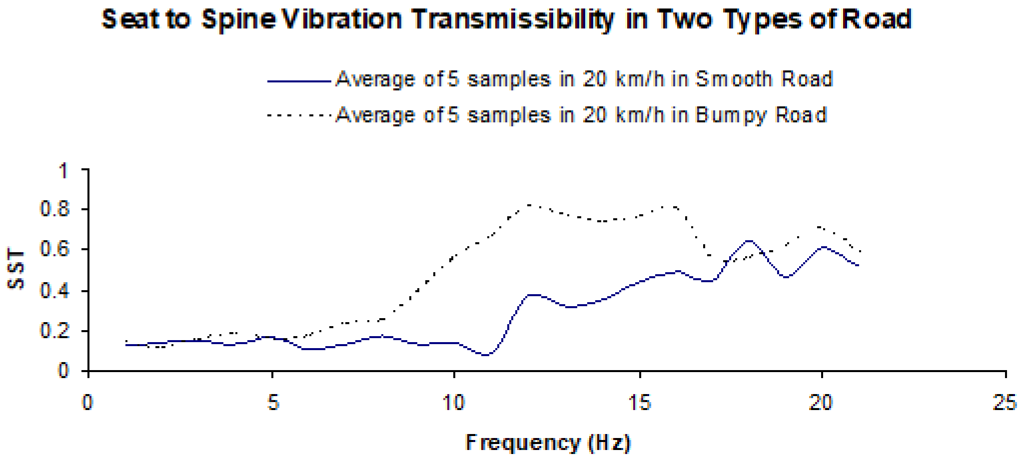

Fig. 9: Comparison between SST in smooth road and bumpy road, 20 km/h forward velocity

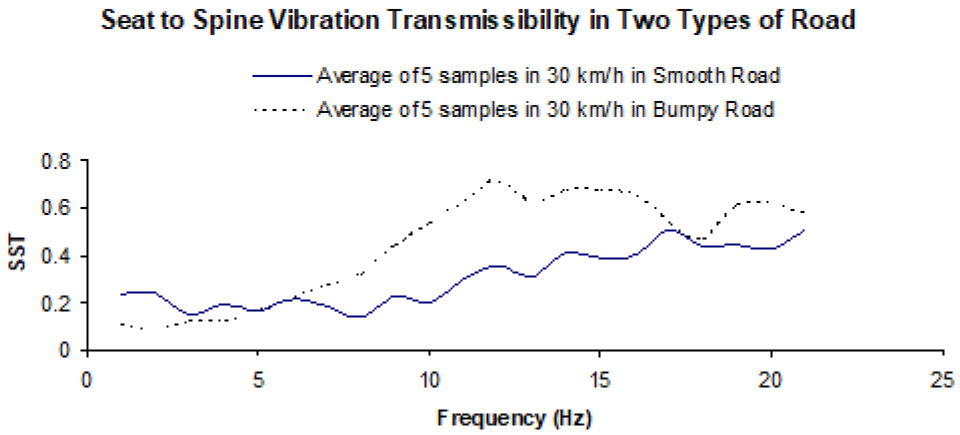

Fig. 10: Comparison between SST in smooth road and bumpy road, 30 km/h forward velocity

The current optimized suspension parameters were also compared to a published study [22]. The seat mass, damper and spring coefficients in this work, were 14 kg, 125 Ns/m and 8130 N/m, respectively, by the Quasi-Newton method to minimize seat-to-head transmissibility. Parameters set up by this study for seat suspension to minimize seat-to-spine vibration transferring demonstrate a heavier value in mass as 2 kg. However, stiffness in spring is lower, and it was 8000 N/m. Additionally, the damper constant was 130 Ns/m, so it was a little higher. [23] improved seat suspension via a genetic algorithm and decreased force transmitted from the pelvis to the thorax near 7.5% in the desired frequency range. In another study, [24] obtained seat mass, damper and spring parameters by using the Wan-Schimmel model and ANN optimization as 8 kg, 130 Ns/m and 8000 N/m, respectively. The aim of their study was minimizing seat to head vibration transmissibility. Fortunately, the result of this optimization shows better findings to eliminate vibration at the spine compared with cited studies.

4. Conclusion

One of the techniques which is helpful for optimization is artificial neural network. This approach is appropriate when the mathematical model is not accessible but experimental data is available. ANN optimization method for minimizing the spine vibration caused by seat vibration was applicable. It is apparent that the acceleration of the spine after optimizing shows a large reduction. Referring to the found results, spine vibration transmissibility can be kept lower than one by regulating seat suspension factors. Furthermore, ANN optimization can be done by using biodynamic ANN model for human body responses to vertical vibration.

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