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Analysis of the dynamic behavior of the car user in the irregular terrain

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Abstract

Many people experience vibration effects on whole-body throughout their lives frequently. Vibrating energy absorbed is exposed all-body caused with vibration hazard in the vertically on body and biodynamic responses from body in speed 2.37 to 5.14 m/s could captivate with car seat on user body, so the vibration energy transferred to a seated people body. In this paper, the human body is modeled as a series/parallel 4 DOF dynamic models of system and use Lagrange equation for calculate head and neck equation and investigation the effect of vibration energy absorbed in whole body. The hybrid model is analyzed with Matlab software for vertical vibration responses and vibration energy absorption. It is shown improvement seat vehicle cause, drastically ameliorate the tolerance to high-intensity vibrations in the 0.8 Hz range with reducing the maximum amplitude ratios and relative displacements of the body.

Keywords: *Transient analysis; People body vibration; Vibration answer; Mathematical model*

1. Introduction

Vehicle vibration has direct impact on human riding comfort, driver fatigue and safety. People are more sensitive than all body vibration subject to short-frequency affection under the seated position. Vehicle user is expose to high-intensity vibration grades in the 0.8 Hz range for extended periods of time, which he is not physically equipped to tolerate. It is not amazing that a consider with orthopedic surgeons in the United States creates that car drivers ache as amount of clutter of the spine and assisting construction. In fact, great amount of osteoarthritis, damaging fibrosis, herniated disks, lumbosacral pain, abdominal pain, and intestinal chaos event in drivers of trucks, tractors, motorcycles, and other vehicles or machinery in which apparent vibrations and jolts event [1,2,3]. Biodynamic of seated people under had a topic of attention over the years, and amount of mathematical models have been created. The concept of absorbed energy was investigates with a group of researchers, who indicated results as analysis that showed the biased knowledge of vibrations are affiliated to many vibration energy absorbed with the body [4,5]. Biodynamic answer of the people body in seat situation has more amounts subject to all-body vibration. Vibration power absorption into the al of body vibration structure is one of the most important biodynamic measures that could use to allotment the vibration airing for computing its power influences [6]. Although the accurate association between the amount of absorbed energy and the caucus or collection detriment ashes alien, the vibration energy absorb could be easily regard as a

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physical measure of vibration-effected mechanical arouses that dons exactly on the caucus and collections. Expertise vibrations are carrying to and among the people, body could bring an important insert to our awareness of people answer to all-body vibration [7]. Vibration intensity is identifying with the abundance ratio, acceleration grade, applicable abundance among the abutting body parts and pitch of the car. Each alienation of vibration with given a suspension could decrease all these distinctive. It is see that the acceleration grades in accepted cars are about 0.71 g, and standard seats give rise to amplitude ratios of 2.5 to 4.7. These vibration acceleration grades are of much higher intensity than the one-minute 'exposure limit' proposed with the International Standards Organization, ISO [8]. Therefore, it is proposed, in this study, to reduce the acceleration levels to much below 7-h 'exposure limit' proposed with suitably selecting its variables [9,18]. In many articles has shown that a mechanical action of the people body distinctive with the seat is essential also the calculated biodynamic answer have been applied to classify crucial frequency ranges assistant with resonances of various body parts [10]. A simple sample that taking the important dynamics of a seated people under to all body vibration is the 4-DOF dynamic model of the people body expanded with Wan and Schimmels, or with Boileau and Rakheja or others researchers that we will continue to refer to them and analysis results [11,19].

In this paper indicated here, the user and the car are model with in the form of a lumped mass classification interconnected with springs and damper. The composite model, consisting of people body, car, and its seat suspension is under sinusoidal vibration at the tire relate points. The result responses of each body part, achieve with computer simulation, are studied to select the parameters of the seat suspension such that the occupant vibration intensity such as: force, displacement, velocity, acceleration and abundance ratios is decreased to a minimum in frequency range and biodynamic answer had decided as a function of the car operating speed.

2. Biomechanical modeling

A amount of biodynamic models had presented in the article to evaluated the amount of forces carried to special sub classifications within the body, to create power destruction mechanisms, and to compute the tolerance to vibration subject to publicity to intense vibration grades. The researchers have studied the people body in a sitting position could be assembled as a mechanical classification that is collected of many austere bodies interconnected with springs and dampers [12, 13]. International Organization for Standardization (ISO) published a parallel 2-DOF model for both sitting and standing positions. Nawayseh applied a series/parallel 4-DOF people dynamic model designed to relate the answer of seated people under to vertical vibration [14]. In this model develop applied a series/parallel 4-DOF people dynamic the seated people body was created with four isolate mass parts interconnected with four sets of springs and dampers ,moreover one of the degrees of freedom applied in semi active damper part with all people mass of 60.76 kg. The four masses constitute the four masses body parts head and neck, upper torso, shorter torso and thighs and pelvis. The arms and legs are amalgamated with the upper torso and thigh, respectively. Moreover, 4-DOF people-body model include four mass parts interconnected with four sets of springs and dampers with all mass of 65.4kg [15,18]. The model variables were achieved with comparing action results with the results of experimental examines on people subjects. The topologies of the 4-DOF models are illustrate in Figure.1, and the biomechanical variables of the model are listed in Table 1.

Table1.parameter values biomechanics of the body

Body parts	Mass (kg)	Damping (kg/s)	Stiffness (N/m)
Head and Neck	$M_h = 5.63$	$C_h = 320$	$K_h = 230000$
Shorter torso	$M_2 = 26.74$	$C_2 = 2480$	$K_2 = 96500$
Upper torso	$M_3 = 7.06$	$C_3 = 2750$	$K_3 = 174800$
Pelvis	$M_m = 21.33$	$C_m = 1200$	$K_m = 50000$
Suspension		$C_c = 2775$	$K_C = 50005$

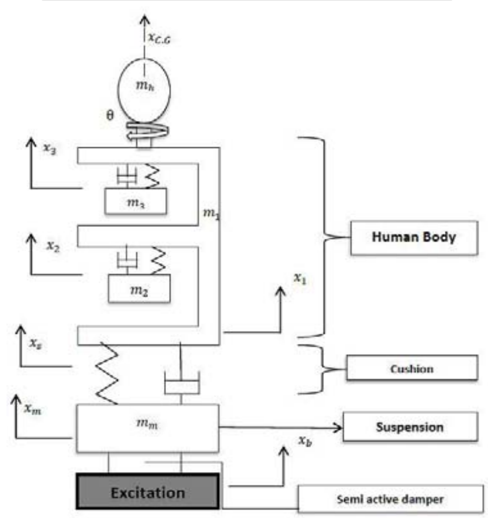

Figure.1 Biomechanical models

3. User- car hybrid model

The hybrid model of the user- car, affecting on a wavering ground, is indicate in Figure 1. The composite model is investigates for transient vertical vibration answer of the body parts and seat to square pulse insert $\left\{\frac{1}{s}\right\}$ type of pulse insert applied to car tires.

Moreover, the data applied for identification of the energy absorbed with the body was collected from a series of normal outlines for functional driving situation [16]. The user- tractor operates at various operating speeds.

Hence, investigate the energy content of the vibration carried to the all body and various body parts, a four-degree of freedom linear biodynamic models is choose to constitute the body. The local absorbed energies and the all energy absorption subject to various affections are calculated. The weighted value of acceleration a_w could apply to evaluate the people riding comfort of a driver.
The vector sum of weighted values of acceleration could achieve thus [18]:

$$(a_w)_{wek} = \sqrt{\left[1.4(a_w)_x\right]^2 + \left[1.4(a_w)_y\right]^2 + \left[(a_w)_z\right]^2} \qquad (1)$$

That result listed in table 2 and shown in figure 2.

4. Biodynamic answer analysis

The classification equations of movement for the model could represent in matrix as Eq.(2):

$$M\ddot{x} + C\dot{x} + Kx = F \qquad (2)$$

Where, $[M]$, $[C]$ and $[K]$ are mass, damping, and stiffness matrices, respectively. Furthermore, x_1 And x_S are the displacements of whole body and seat and $\dot{x}_1$, $\dot{x}_S$ and $\ddot{x}$ refer to velocities of all body, seat, and

Table 2.vector-sum vibration amount, the

Speed (m/s)	Acceleration in vertical direction $(a_w)_z$	Acceleration in direction $(a_w)_{wek}$	Vibrational energy absorbed with the people body
2.37	0.5	1.243	13.7
3.06	0.611	1.432	29.87
3.76	0.823	1.641	62.82
4.45	1.338	2.058	78.02
5.14	1.470	2.18	94.32

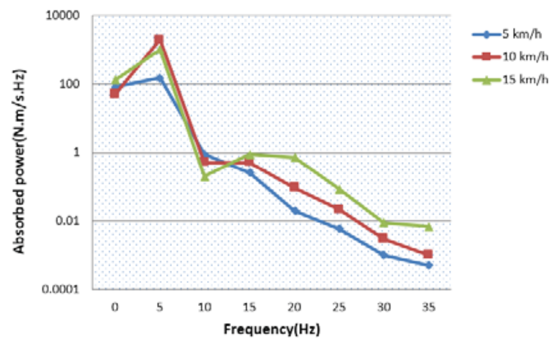

Figure 2. Absorbed power calculated at pelvis period work with the aggregate at various working speeds

acceleration and vibration energy absorbed with the body with the aggregate at different working speeds acceleration of all body, respectively; F is the force vector due to outer affection. With taking the Fourier alteration of equation (1), the following matrix form of equation could be achieved [19]:

$$\left[X(j\omega)\right] = \left[K - \omega^2(M) - j\omega(C)\right]^{-1}\left[F(j\omega)\right] \qquad (3)$$

Where, $\left[X(j\omega)\right]$ and $\left[F(j\omega)\right]$ are the complex Fourier alteration vectors of $[x]$ and $[F]$ respectively, and ω is the affection frequency. Vector $X(j\omega) = \left[X_1(j\omega), X_2(j\omega), X_3(j\omega), \cdots, X_n(j\omega)\right]$ contains complex displacement answer of n mass parts as a function of $\omega.F(j\omega)$ include complex affection forces on the mass parts as a function of (ω) as well, and for the Wan Schimmels model is $F(j\omega) = \left[0,0,0,(k_5 + j\omega c_5)X_{se}(\omega)\right]$ where $X_{Se}(\omega)$ is the abundance of insert displacement affection [17].The instantaneous power (T_{Tr}), carried to the people body period vibration could computed from the goods of the force (F) displacement (x) ,velocity (V) and acceleration (a) calculated at the interface among the body and the vibrating surface. The velocity was achieved with accommodating the calculated acceleration time history. The instantaneous power (P_{Tr}) carried to the structure is conventionally defined as: [13,18]

$$P_{Tr} = F(t).V(t) = P_{Abs}(t) + P_{EI}(t) \qquad (4)$$

$P_{Abs}(t)$ is the absorbed part of the power, chronicling for the energy essential for keeping pace with the energy consumed among structural damping. The elastic power $P_{EI}(t)$ is extending send to, deleted from the structure period any time of affection, and means zero for any sinusoidal cycle of movement. Therefore, the time averaged absorbed power ($P_{Abs}(t)$) identical the carried power (P_{Tr}) : [18]

$$(P_{Abs}) = (P_{Tr}) = (F(t).V(t)) \quad (5)$$

The power carried to the body could computed in the frequency area from the cross-spectrum among the force and the velocity, displacement and acceleration. The real part of the carried power constitutes the power absorbed with the body: [13]

$$P_{Abs} = \mathrm{Re}[G_{VF}(F)] \quad (6)$$

Where (P_{Abs}) is the absorbed power, $\mathrm{Re}[G_{VF}(F)]$ is the real part of the cross-spectrum. The absorbed power spectrum (P_{Abs}) has units of $\left(\frac{N.m}{s.Hz}\right)$. The fanciful part of the carried power constitutes the power that inserts and leaves the body. The all power absorbed at each insert interface was achieved with accommodating the absorbed power spectra over the frequency range [15]. In addition to the equation of movement for each mass, include the apathy word and forces utilized on the mass with the springs and dampers due to the applicable movement of the connected masses. We derive the governing equations of motion for head and neck, shorter torso, upper torso, pelvis and seat as follow:

$$T = 0.5M\dot{x}_{CG}^2 + 0.5m(\dot{x}_{CG} + l\dot{\theta})^2 \quad (7)$$

$$U = 0.5k_t\theta^2 \quad (8)$$

$$\delta w_{nc} = 0 \Rightarrow \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} + \frac{\partial U}{\partial q_i} = Q_i \quad (9)$$

$$i = 1 \Rightarrow q_1 = \theta \overset{4}{\Rightarrow} \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_1}\right) - \frac{\partial T}{\partial q_1} + \frac{\partial U}{\partial q_1} = Q_1 \quad (10)$$

$$\frac{\partial T}{\partial \dot{q}_1} = ml(\dot{x}_{CG} + l\dot{\theta}) \quad (11)$$

$$\frac{\partial T}{\partial q_1} = 0 \quad (12)$$

$$\frac{\partial U}{\partial q_1} = k_t\theta \quad (13)$$

$$Q_1 = 0 \quad (14)$$

$$\xrightarrow{6,7,8,9 \text{ in } 5} m_h l\ddot{x}_{CG} + m_h l^2\theta + k_t\ddot{\theta} = 0 \quad (15)$$

Other parts we had to express the equations of motion equations (16) to (19).

$$m_1\ddot{x}_1 + C_c(\dot{x}_1 - \dot{x}_s) + K_c(x_1 - x_s) = F_2(t) + F_3(t) \quad (16)$$

$$m_2\ddot{x}_2 + C_2(\dot{x}_2 - \dot{x}_1) + K_2(x_2 - x_1) = F_2(t) \quad (17)$$

$$m_3\ddot{x}_3 + C_3(\dot{x}_3 - \dot{x}_1) + K_3(x_3 - x_1) = F_3(t) \quad (18)$$

$$m_m\ddot{x}_m + C_c(\dot{x}_m - \dot{x}_b) + K_c(x_m - x_b) = F_{friction}(t) \quad (19)$$

5. Transient analysis

The relevance of this study is to choose the design variables of seat suspension such that body parts do not ache detriment due to hasty high-abundance applicable displacements among them at the onset of vibrations, when the car is contend with hasty barriers for a short while, although this is also supported and substantiate. The obstructions or ground irregularities are idealized with square pulse insert $\left\{\frac{1}{S}\right\}$ type of inputs with maximum amplitude of $1N$ (figure.3). This type of insert constitutes two checks (surface exceptional) of height 1 N, width 0.31m each and separated by 1.56 m. When the front tire is on the peak of the first obstacle, the second obstacle will be located at 0.44 m (a + b - 1.56 = 0.42 m) ahead of the back tire. The front tire is subject to the first insert irregularity and the back tire to the second after a time lag of 0.09 s , characterizing the time taken by the vehicle rear tire to reach the irregularity when it is moving at a speed of 15 $km/hour$. The distances between obstacles and speed of vehicle are choose such that it represent the most adverse type of insert condition to which the car tires could subject.

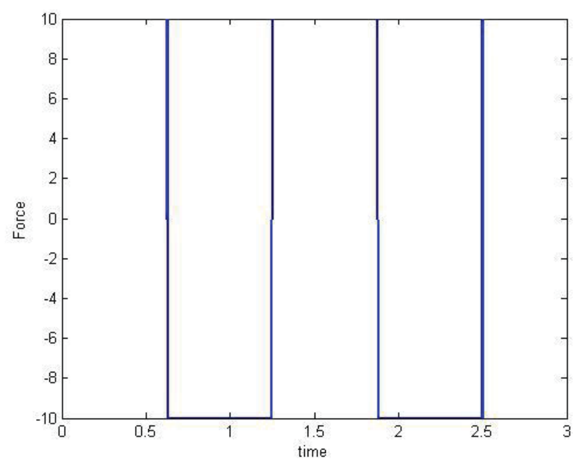

Figure 3.Force insert at the car tires for transient answer

The vibration force inserts at front and back tires are mathematically rededicated with x_1 and x_2 given as follow:

$$x_1 = \frac{10At}{T}\left[u(t)\right] + A\left[u(t) - u(t-0.5T)\right] + 10A(1-T)\left[u(t-0.5T) - u(t-T)\right] \quad (20)$$

$$x_2 = \frac{10A(t-1.5T)}{T}\left[u(1.5t) - u(t-1.5T)\right] + A\left[u(t-1.5T) - u(t)\right] + \frac{10A}{T}\begin{pmatrix} 2T-t \\ \left[u(t) - u(t-2T)\right] \end{pmatrix} \quad (21)$$

Where $u(t)$ represents the units step function, defined as:

$$u(t) = \begin{cases} 0 \rightarrow t < 0 \\ 1 \rightarrow t \geq o \end{cases}$$

And $f = 0.8HZ$, $A = 0.75N$, $T = 1.25 \sec s$ .The governing vibration equations of the composite model, for the square pulse input type of displacement inserts at the vehicle tires, remain same as equations (2) to (19) for whole body and car seat. The equations for the car chassis as follow (figure. 4):

$$M_{ct}\ddot{x}_g + C_{St}(\dot{x}_g - \dot{x}_S - c\dot{\theta}) + C_{gf}(\dot{x}_g + b\dot{\theta}) + C_{gr}(\dot{x}_g - a\dot{\theta}) + K_{St}(x_g + x_S - c\theta) + K_{Sb}(x_g - x_S - c\theta) + K_{gf}(x_g + b\theta) + K_{gr}(x_g - a\theta) = C_{gf}\dot{z}_1 + C_{gr}\dot{z}_2 + K_{gf}z_1 + K_{gr}z_2 \quad (22)$$

$$M_{Ct}\rho^2\ddot{\theta} + bC_{gf}(\dot{x}_g + b\dot{\theta}) - aC_{gr}(\dot{x}_g - a\dot{\theta}) - cC_{St}(\dot{x}_g - \dot{x}_S - c\dot{\theta}) - cK_{St}(x_g + x_S - c\theta) - cK_{Sb}(x_g - x_S - c\theta) + bK_{gf}(x_g + b\theta) - aK_{gr}(x_g - a\theta) = bC_{gf}\dot{z}_1 - aC_{gr}\dot{z}_2 + bK_{gf}z_1 - aK_{gr}z_2 \quad (23)$$

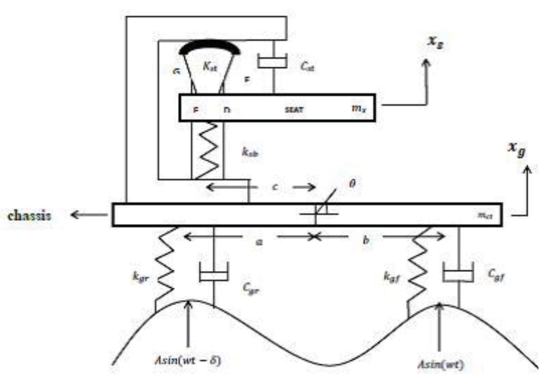

Figure.4 seat and chassis model [19]

Where $\dot{z}_i$ and z_i constitute the corresponding velocities and displacements at the car tires. Equations (14) and (15) along with equations (1) to (11) are programmed on the computer using action and solved to give y, the transient abundance answer of the segment driver body and seat and the applicable displacements among abutting body parts. The variables of the seat suspension are decided such that the applicable displacements among body parts are minimize in the 0.8 Hz frequency range.

6. Results

The groups of body parts, which give maximum applicable displacements among themselves, are only choose, here, to constitute their answer. Figure.5 constitutes the displacements transient answer of pelvis(x_1)-seat (x_s) combination. The maximum answer of seat is found to be higher than the body part (pelvis). All the answer dies down to zero at 3 s. It is found, among all body parts, pelvis is subjected to the highest abundance of 0.02 mm event ring at 0.179 s, after the pulse insert is applied at the tires and it dies down to zero at 2.8 s. In figures show pelvises and seat with "x_1" and "x_s" respectively.

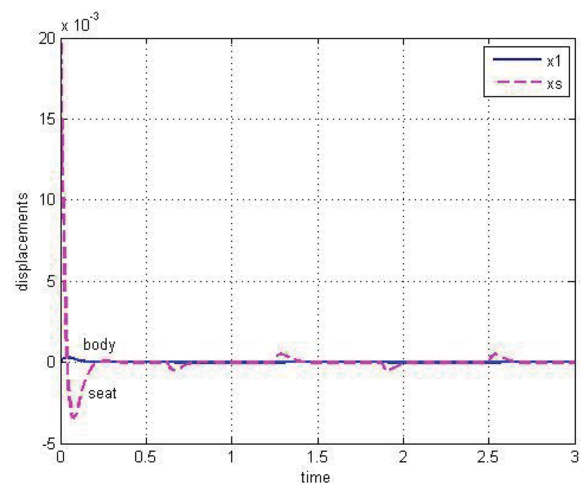

Figure5. Displacements transient answer on people body

Figures 6 represent the velocity transient response of pelvises-seat that it is effect on human body, It is found part body subjected to the highest amplitude of 0.7mm occurring at 0.187s,after the pulse input is applied at the tires and it dies down to zero at 2.5s. Furthermore, in figures 7 represent the acceleration transient response of pelvises-seat that it is effect on human body. It is value is computed at 2.2mm occurring at 0.12s. Finally, the figures 8 represent the force transient response of pelvises-seat that it is effect on human body, It is value is computed at 0.14N occurring at 0.12s.

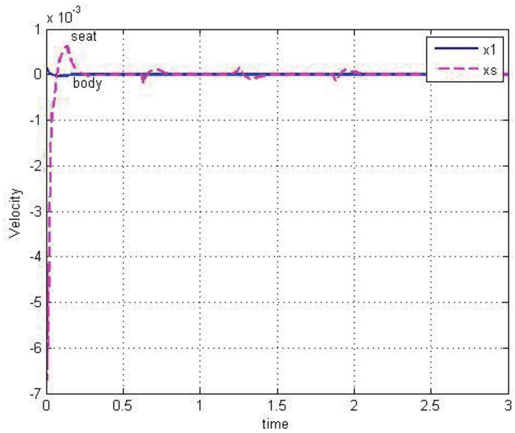

Figure 6. Velocity transient answer on people body

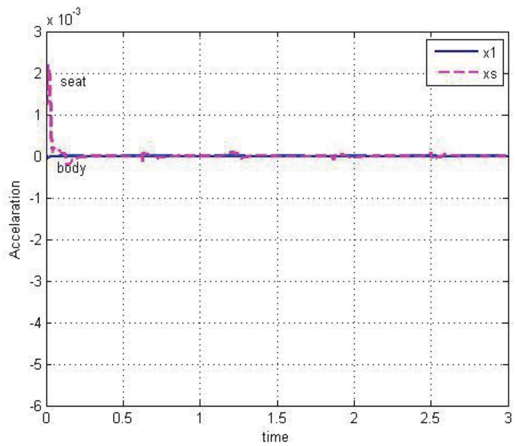

Figure 7. Acceleration transient answer on people body

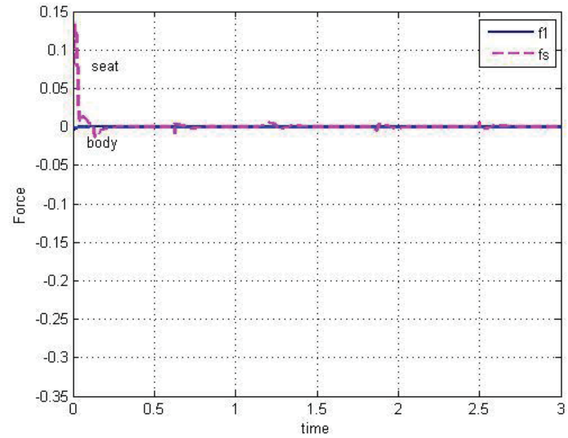

Figure 8. Force transient answer on people body

Taking the length between these parts as 16cm the strain value is computed as 0.116% which is found to be far less than the strain percentage or breaking index (37%) indicated in other article for the same body parts.[7].Table 3 presents summary transient response of vehicle seat and occupant body parts. According to table 3, the amount of amplitude ratio decreases to 0.031. Moreover, the relative amplitude between adjacent body parts and transient amplitude are reduces to 0.2 mm and 0.47mm, respectively.

Table3 .transient answer of car seat and user body parts

Transient			
Applicable abundance among all body parts			
dynamic distinctive		Time of occurrence(s)	Applicable abundance(mm)
displacements	body	0.27	0.00029
	seat	4.66	0.0034
	suspension	4.71	0.02
velocity	body	0.5	0.00013
	seat	4.7	0.0006
	suspension	4.87	0.0006
acceleration	body	0.53	0.000432
	seat	4.6	0.0051
	suspension	4.925	0.0038
force	body	0.45	0.0032
	seat	4.81	0.313

7. Conclusions

The conception of absorbed energy as an amount for evaluation of WBV during opens a new zone for scientist also a mathematical model of the car - operator classification, with a seat for vibration answer, is expand for affection of seat variables, that people body vibration answer. A suitable way to contrast this conception with other quantity of vibration airing in relation to health influences would be to attitude epidemiological examines on various classification of experienced drivers. Knowledge of the structural model of the user affords affection of the dynamic distinctive of the model, and study of the energy flux among the elements of the model. In the indicated paper, measurement method for choosing vibration power consumed in the people all body classification called Vibration Energy Absorption (VEA) and investigates with computer action for vertical vibrational answer for a seat and analysis answer effect on all body. The results indicates the all body vibration was about 3 times higher in the vertical direction when working at a speed of 5.14 (m/s) than at the speed of 2.37 (m/s). Furthermore, the acceleration intensity level decreases to below 7-h exposure limit curve and pitch response of the chassis reduces to 0.661°/cm of input amplitude. Moreover, results shown improvement seat vehicle cause drastically ameliorate the tolerance to high-intensity vibrations in the 0.8 Hz range with reducing the maximum amplitude ratios and relative displacements of the body parts to 0.031 and 0.20 mm, respectively. Thereby, the mathematical model analysis has given useful results that could possibly applied for better design.

References

[1] Radke,A,O,1957, “Car vibration environment”,ASME paper,14 ,57-A,1-9

[2] Von Gierke,H,E.1959, “Transmission of vibratory energy among people body collection,proc”,first National Biophysics Conf,yale university press, new Haven,conn,22 ,pp.66-76

[3] Lundstrom R, Homlund P, 1998, “absoption of energy during all-body vibration airing”, journal of sound and vibration, 22, 78-79.

[4] ISO, 1972, “Guide for the Evaluation of people airing to all body vibration”. International standards organization DIS 2631

[5] Mathews, J, 1973, “the measurement of tractor rid comfort”, SAE meeting Milwaukee, Wis, paper no, 73, pp.1-15.

[6] Mathews,J,1967, “ progress in application of ergonomics to agricultural engineering”, agricultural engineering symp,silsoe, 11 ,pp.64-66

[7] Cieslikowski B, 2009, “Modelling of the vibration damping in an operator’s seat classification”, journal of energ, roln olpan, 9, pp.22-31.

[8] ISO 2631-1,1997, “mechanical vibration and shock”, part3,general

[9] Liang CC, Chiang CF, 2006, “A study on biodynamic models of seated people subjects under to vertical vibration”, international journal of industrial ergonomics, 36, pp 87-96.

[10] Boileau, Rakheja, 1967, “absorbed power and mechanical impedance of the seated people under to all-body vibration in vertically directions”, journal of agric.eng.res, 12, pp. 41-58.

[11] Tajanowskij G, tanasW, 2010, “the analysis of regular wheel loadings distribution at astatically unstable running classification if an agricultural machine on rough surface. Take commission of motorization and power industry in agriculture”, polish academy of sciences branch in Lublin, 10,pp 46-61

[12] Szczepaniak, kromulski, 2011, “analysis of energy flux model in the biomechanical classification people operator”, journal of research and application in agricultural engineering, 55, pp.136-142.

[13] Boileau, Rakheja Xie X, 2001, “absorbed power as a measure of all body vehicular vibration airing”, PhD thesis, Departteman of mechanical engineering, Concordia University Montreal, Quebec, Couldada.

[14]Nawayseh, Griff MJ, 2010, “power absorbed during all-body vertical vibration influences of sitting position of sitting”, journal of sound and vibration, 329, pp.292-298.

[15] Rakheja, Mandapuram S, Dong, 2008, “energy absorption of seated users under to horizontal vibration and role of back support condition”, journal of industrial health, 11, pp.550-561.

[16] Dong, McDowell TW. Schopper, 2006, “Frequency weighting derived from power absorption of fingers-hand-arm classification subject to z-axis vibration”, journal of biomechanics, 39, pp.231-235.

[17] Muksian and Nash, C, D, 1974, “a model for the answer of seated people to sinusoidal displacements of the seat”, journal biomechanical, 7, pp.206-215.

[18] Szczepaniak J, Tanas W, Kromulski J,2014, “Vibration energy absorption in the all body classification of a tractor operator ”, annals of agricultural and environment medicine, 21, pp.399-402.

[19] Liang CC, Chiang CF, 2008, “Modeling of a seat people body under to vertical vibration in various automotive positions”, journal of industrial health, 46, pp.125-137.