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PREDICTION AND ANALYSIS OF APPARENT MASSES (AM) OF ANTHROPOMETRIC BASED HUMAN SEATED POSTURE

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Abstract:

*The vibrations in the moving parts such as vehicles, machinery is exposed to the various injuries, back pain, muscular disorder etc. The effects of such vibrations are more in the case of driver specially truck driver. In the present work, the investigation is carried out for the human seated posture. Six degrees of freedom (6-DOF) was developed for the human sated posture. Most of the researchers are working in the same direction to minimize the impact of vibration created from the moving vehicles. The apparent mass (AM) was focused for the investigation. Higher value of the response AM causes discomfort and various issues related to the health. The parameters such as the age of the driver, weight, stiffness coefficient of the body segments and the damping coefficients are considered for the investigation. Taguchi's mixed plan of design of experimentation L_{18} (2^1*3^3) was chosen for the experimentation. Two groups of male subjects (more than 50 years and less than 50 years age) were selected for the investigation. Three drivers with weights less than 60 kg, weight between 60-70 kg and the weight greater than 70 kg were selected for the experimentation. The well-known desirability function (DF) was employed to find out the optimum parameters which minimize the response AM. The human body is a very complex structure so two-dimensional model with six degrees of freedom is selected in the presented work. The present work will help the industries to design the anti- vibrational device. The presented work may also be lengthened to develop similar models with others degrees of freedom.*

Keywords: Six-DOF, Age, Weight, Stiffness, Damping coefficient, RSM, Desirability function.

1. INTRODUCTION

Prolonged vibration in human seated posture cause very serious injurious in the body such as back pain, visceral dysfunctions, musculoskeletal disorders etc. So many health issues have been reported in the case of moving vehicles drivers, tractor and truck driver and other moving vehicles drivers. N. Shibate [2] analysed the impact of phase difference on the biodynamic responses such as seat to head transmissibility and the apparent masses. The author considered the dual –axis vibration to analyse the effect of phase angle differences between two translational vibrations. From their study, it has been observed that the phase angle difference affected the biodynamic response. S. Mandapuran et al. [3] investigated the biodynamic responses of a human seated posture. The whole body was subjected to the vibration in three directions. None adult male subjects were considered for the investigation. Dewangan et al. [4] investigated the impact of gender and the anthropometric features of a human seated posture on the biodynamic response apparent mass. 31 male and 27 female subjects were considered for the investigation. The response was analysed by grouping the datasets into three groups i.e. mass related data, build and stature related biodynamic parameters for the male and female subjects. H. Taghavifar et al. [5] developed ANN based model for predicting the biodynamic response of seated human posture considering the anthropometric, sitting and the conditions of vibrations level. The model has been investigated between the vibration range of 0.5 to 20 Hz frequency. C. Mehta sand V. Tewari [6] has predicted the loads likely to be created in various body parts under the various vibrational conditions. The biodynamic model was developed to analysis the shear and compressive load on the body part such as lumbar vertebra of a tractor driver. R. Dong et al [7] developed three dimensional finite element models for human seated posture to investigate the impact of seating posture on the biodynamic responses. The model was tested for the vibration range between 0 to 20 Hz. S. Daeijavad and A. Maleki [8] have investigated the impact of uncomfortable tractor chair and the design parameters of the comfortable tractor chair which minimize the effects of vibrations. Finite element method (FEM) was used for analysis and investigation of tractor chair. From the experimental findings, it has been observed that the angle of backseat and the seat-pan was the most influencing parameters. J. Krajur [9] has carried out the investigation of the tractor operator health and the whole-body vibration. The researcher investigated the influence of various postures of the human body on the acceleration values. During the experimentation vehicle speed and the simulated test track was kept constant for getting the accuracy in the results. Miroslav Demic and Jovanka Lukic [10] optimized the motor vehicle system design. The effect of fore and aft vibrations is investigated by using electrro-hydraulic simulator. The experiments were conducted with and without inclination. The experimental findings shows that the human body response like a non linear system under the vibration. S. Rahmatalla and J. Deshaw [11] has investigated the impact of vibration on the seat to head transmissibility. The novel approach of multiple input and multiple output for the whole body vibration system was employed for the investigation. The response was measured in terms of transmissibility. The experimental findings show that the sitting posture and arm position were the most influencing parameters. L. Roseiro et al. [12] analysed the exposure level of the vibration induced in the cycle driver and the motor driver hand. From the investigation, it has been observed that vibration level inducted during the driving on stone road was exceeding the limit. Various types of road nature, type of bicycle and the operators were examined during the investigation. V. Kumar and V. Saran [13] investigated the impact of reading format on reading activity under the uni-axial whole-body vibration. 30 male subjects were examined during the reading activity for the vibration range 0-20 Hz. The experimental findings were useful for the passenger read during the journey. A. Rhimi [14] examined the prolonged static posture of the car driver. The basic aim of their work was to find out the optimum design parameters of the car seats that might reduce the impact of discomfort generated during the driving. FEM model were developed to carry out the investigation. E. Weston et al. [15] examined the office seat and tablet device for the comfort. 20 subjects were examined during the typing task on a desktop computer and touch screen tablet in two chairs for an hour each. The effect of seat, device and their interaction were examined during the analysis. Heart rate variability was examined as a response parameter.

G. Kamalakar and A.Mitra [16] used MATLAB-SIMULINK model for predicting the human biodynamic responses. 4-DOF human seated model has been tested to minimize the impact of vibrations on the health. W. Abbas et al. [17] tested 4-DOF and 7 –DOF human seated biodynamic model and optimized these models using genetic algorithm technique. The objective of their research work was to minimize the apparent mass response. M. Gohari et al [18] developed lumped model based on the artificial neural network to study the impact of seat to head transmissibility. From their experimental findings, it has been observed that the ANN based model is a very effective and efficient approach coupled with biodynamic concept to study the similar kind of subject. Abdeen and W. Abbas [19] used artificial neural network to test the biodynamic responses. 4-DOF human seated biodynamic model were tested for the analysis. The results shows the precision and accuracy of the predicted responses. A.S. Prashanth [20] has developed 5-DOF human seated biodynamic model to analyse the impact of driving point mechanical impedance (DPMI). The experimental and the model predicted responses were correlated and the model accuracy was tested. Along with the 5 –DOF model, 4 and 7 DOF model were tested for critically analysing the impact of vibrations on the health.

MATERIAL & METHOD

In this section, the methodology adopted for the calculation of mass, stiffness and damping coefficient of all segments on the basic of anthropometric features tabulated in Table 3. Phate et al. [1] has discussed about the calculations related to the six degrees of freedom biodynamic models.

1.1 **Biodynamic Six Degrees of Freedom Model:** It is very difficult to analyse the complete human body subjected to the vibration. To maintain the accuracy in the analysis and to analyse the impact of vibrations on the human body, the body is divided in to six segments as shown in the Figure 1.

Figure 1 illustrates the human seating posture six-degree biodynamic model. The body is divided into six segments i.e. head (P1), upper torso (P2), thorax (P3), diaphragm (P4), abdomen (P5) and the thigh (P6). The model consists of mass elements, stiffness and damping coefficient of an individual body segments. According to De-Alembert principal, the equation of motion for all the segments is given by Equation 1 [1].

$$\left.\begin{aligned}
m_1\ddot{X}_1 &= -C_1(\dot{X}_1-\dot{X}_2)-K_1(X_1-X_2)\\
m_2\ddot{X}_2 &= C_1(\dot{X}_1-\dot{X}_2)+K_1(X_1-X_2)-C_2(\dot{X}_2-\dot{X}_3)-K_2(X_2-X_3)\\
m_3\ddot{X}_3 &= C_2(\dot{X}_2-\dot{X}_3)+K_2(X_2-X_3)-C_3(\dot{X}_3-\dot{X}_4)-K_3(X_3-X_4)\\
m_4\ddot{X}_4 &= C_3(\dot{X}_3-\dot{X}_4)+K_3(X_3-X_4)-C_4(\dot{X}_4-\dot{X}_5)-K_4(X_4-X_5)\\
m_5\ddot{X}_5 &= C_4(\dot{X}_4-\dot{X}_5)+K_4(X_4-X_5)-C_5(\dot{X}_5-\dot{X}_6)-K_5(X_5-X_6)\\
m_6\ddot{X}_6 &= C_5(\dot{X}_5-\dot{X}_6)+K_5(X_5-X_6)-C_6(\dot{X}_6-\dot{X}_{se})-K_6(X_6-X_{se})
\end{aligned}\right\} \quad (1)$$

Fig.1. Six Degrees of freedom (6-DOF) Human Seated Posture biodynamic model [1].

The mass, stiffness and the damping coefficients of all the body segments are calculated as per [1].

1.2 Biodynamic Response Apparent Mass (AM) Calculation:

The Equation (1) can be expressed in matrix form as Equation

$$M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = \{f\} \quad (2)$$

Where, [M], [K] ,[C] and [f] are the mass, stiffness, damping coefficient and the input excitation force matrix. The Fourier transform of the Equation (2) is given by the following Equation (3).

$$(-\omega^2 M + j\omega C + K).Z(j\omega) = Fz(j\omega) \quad (3)$$

Where j= (√-1) is the complex phasor and ω is the angular frequency. The solution can be obtained as given by "Equation (4)".

$$\left.\begin{aligned}
Z(j\omega) &= [Z1(j\omega), Z2(j\omega), Z3(j\omega), Z4(j\omega)]^T\\
Fz(j\omega) &= [0,0,0,(K_4 + j\omega C_4)Z_0(\omega) = \begin{bmatrix}0&0\\0&0\\0&0\\0&0\\0&0\\K_6&C_6\end{bmatrix}\begin{bmatrix}1\\j\omega\end{bmatrix}Z_0(j\omega)
\end{aligned}\right\} \quad (4)$$

Combining Eq. (3) and (4), Z (jω) can be rewritten as:

Combining Eq. (3) and (4), Z (jω) can be rewritten as:

$$Z(j\omega) = A^{-1}B\begin{bmatrix}1\\j\omega\end{bmatrix}Z_0(j\omega)(6)$$

with $A = -\omega^2 M + j\omega C + K$

$$B = \begin{Bmatrix}0&0\\0&0\\0&0\\0&0\\K_6&C_6\end{Bmatrix} \quad (5)$$

From Eq. (4) and (5) correlation among the dynamic response Z (jω) and excitation $Z_0(\omega)$ of the masses can be calculated.

The biodynamic response such as apparent masses (AM) is considered as a response parameter for the investigation. This response helps us to know the impact of vibration on the human body. The vibration impacts the health, comfort and the performance of the human. So, the aim of the present work is to analyse the human seated posture with six degrees of freedom model and find out the comfortable posture which minimize the impact of vibrations. We know that the force essential to accelerate the supporting surface is a complex function of frequency. This function is accessible in terms of the 'apparent mass' which is formulated in "Equation. (6)"as:

$$M(f) = \frac{F(f)}{a(f)} \quad (6)$$

Where M(f) is the apparent mass at frequency (f). But the AM is not the direct function of frequency. For the human seated posture, AM is a function of dynamic characteristics.AM is defined as the ratio of functional periodic excitation force to the resulting vibration acceleration at the same frequency [1] and it is expressed in "Equation. (7) as:

$$AM = \frac{K_6 + (j\omega)C_6}{-\omega^2}\left[1 - [1,0,0,0,0,0]A^{-1}B\right]\begin{bmatrix}1\\j\omega\end{bmatrix} \quad (7)$$

1.3 Human Body Anthropometric Data: The biodynamic parameters with their level of variation are as tabulated in Table 2. The male body with age more than 50 years and less than 50 years were considered for the investigation. The three types of male bodies with weight less than 60 kg, weight between 60 to 70 kg and the weight grated than 70 kg were considered for the analysis. There are three variations in the stiffness and the damping coefficient of the body as shown in the following Table 2.

S.N.	Biodynamic Parameters	Symbols	Levels		
			Low (1)	Medium (2)	High (3)
1	Age (years)	AG	≥ 50 years	< 50 years	------
2	Body weight (kg)	WT	< 60kg	60-70 kg	> 70kg
3	Stiffness (KN/m)	SF	50%less	SF(actual)	50% greater
4	Damping coefficient (N-s/m)	DC	50%less	DC(actual)	50%greater

Table 1. Various biodynamic parameters and their levels.

The male anthropometric data Tabulated in Table 3 was used to calculate the mass, stiffness and the damping coefficient of each body segment. For the detail calculation refers [1]. For each age category three male were chosen for the model testing. The anthropometric dimensions are as shown in Figure 2.

S.N	(Dimensions (cm	Age ≥ 50 years			Age < 50 years		
		BW1	BW2	BW3	BW1	BW2	BW3
L1	Standing height	175	168.8	170.5	176	160	158
L2	Shoulder height	148	138.6	143.7	149.5	134	133.5
L3	Armpit height	138.8	136.8	138	139.6	135.5	135
L4	Waist height	109.8	107.7	109	110.5	106.2	105.6
L5	Seated height	94.8	92.2	94	96.2	91.5	91.1
L6	Head length	19	20.5	18.4	19.2	16.4	16.8
L7	Head breadth	21.5	20.5	21	20.2	18.8	19.2
L8	Head to chin height	20.5	21.2	20.2	20.5	16.5	17
L9	Neck circumference	38.5	37.2	37.9	38.9	36.95	35.95
L10	Shoulder breadth	44.2	43.6	43.2	44.8	42.3	41.2
L11	Chest depth	26.3	22.2	23.3	22.3	26.8	26.8
L12	Torso Height	12.3	11.6	11.5	13	13.5	13.5
L13	Torso breadth	44.8	43.5	41.5	42.8	40.5	42.5
L14	Torso depth	18.5	18.5	18	18.2	18.8	19.4
L15	Torso circumference	52.5	51.8	50	51.9	48.9	48.5
L16	Thorax Height	22.5	18.8	22.5	21.5	22	21
L17	Thorax Breadth	33.5	32.8	31.2	33.2	30.5	30
L18	Thorax Depth	18	20	17.5	17.4	21.5	22.5
L19	Thorax circumference	51.5	50.8	50	51.8	48.5	48.6
L20	Diaphragm Height	9.6	8.5	8.5	8.5	7.5	7.5
L21	Diaphragm Breadth	22.3	22	21.3	21.3	20	18
L22	Diaphragm Depth	14	14	14.5	14.2	14	14
L23	Diaphragm Circumference	41.5	41.2	40	41.9	39.4	39
L24	Abdomen Height	20.4	20.5	21.2	20.2	18.4	17.5
L25	Abdomen Breadth	39.4	39.5	39	38.5	38.5	37.8
L26	Abdomen Depth	26.4	25	27.2	26.5	24.5	24.5
L27	Thigh Circumference	38.8	38	38	36.5	35.5	35.5
L28	Shoulder to Elbow length	33.5	31.5	32.5	33.5	30.5	30.5
L29	Knee Height Seated	54.5	50.4	52.8	53.5	51	49
	Weight	60kg >	kg 60-70	70kg <	60kg >	kg 60-70	70kg <

Table 2. Anthropometric features of the human bodies under consideration.

1.4 Biodynamic response Apparent Masses (AM): Taguchi's design of experimentation (DOE) mixed plan L_{18} $(2^1 * 3^3)$ was chosen for the experimentation. The response (AM) was calculated using equation 7. Fast Fourier transformer (FFT) analyser was used to know the vibrational frequency at the seat point and at the head. A group of six male subjects was taken in to consideration to investigate the impact of vibration and obtain the best posture which minimizes the apparent mass (AM) magnitude. The observations are as shown in the following table 3.

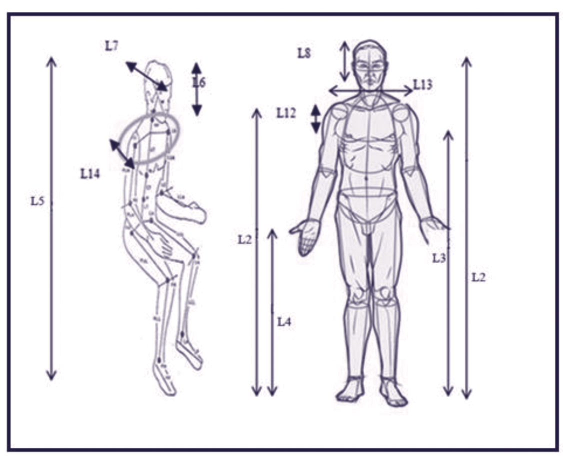

Fig. 2. Anthropometric dimensions of the human posture.

Run	Biodynamic Parameters				Apparent Masses (AM)
	AG	WT	SF	DC	
1	1	1	3	3	73.6521
2	1	2	1	1	72.5681
3	1	2	2	2	73.5281
4	1	2	3	3	74.5254
5	1	3	1	2	73.5261
6	1	3	2	3	74.6854
7	1	3	3	1	74.9852
8	2	1	1	3	75.6231
9	2	1	2	1	75.6321
10	2	1	3	2	75.8965
11	2	2	1	2	74.6581
12	2	2	2	3	75.8523
13	2	2	3	1	76.3254
14	2	3	1	3	74.3625
15	2	3	2	1	76.5841
16	2	3	3	2	76.8521
17	1	1	3	3	73.6521
18	1	2	1	1	72.5681

Table 3. Experimental data and plan of experimentation.

1.5 Response Surface Method (RSM): Response surface method (RSM) is the statistical technique use to correlate the two variables with the response variable. The seconds order mathematical equation is created in this method. This is an industrial tool widely used for the investigation. Minitab software is used for the RSM analysis.

The generalized second degree RSM equation as given by the equation (8).

$$X = a_0 + a_1y_1 + a_2y_2 + a_3y_3 + a_4y_4 + a_{11}y_1^2 + a_{22}y_2^2 + a_{33}y_3^2 + a_{44}y_4^2 + a_{12}y_1y_2 + a_{13}y_1y_3 + a_{14}y_1y_4 + a_{23}y_2y_3 + a_{24}y_2y_4 + a_{34}y_3y_4. \quad (8)$$

Where, X is the response variable is X is the value of input variables and a0,a1,a2.................a34 are the regression coefficient. Response surface method (RSM) two degree model with four process parameters (with coded data or levels and uncoded data or actual value) and the surface roughness as a response parameter is given by the Equation 8 and 9 respectively.

$$AT = 39.99 + 13.53 * AG + 3.942 * WT - 0.626 * SF + 2.380 * IP + 0.1050WT^2 - 0.2283 * SF^2 + 0.1878 * DC^2 - 1.726 * AG * WT + 0.583 * AG * SF - 1.076 * AG * DC + 0.3242 * WT * SF - 0.4139 * WT * DC + 0.1094 * SF * DC \quad (9)$$

2. RESULTS & DISCUSSION

2.1 Response Surface Method (RSM): Four graphs such as Pareto chart, normal plot, and the fits plot and the residual plot obtained during the data analysis through RSM are as shown in figs. 2(a)-2(d).

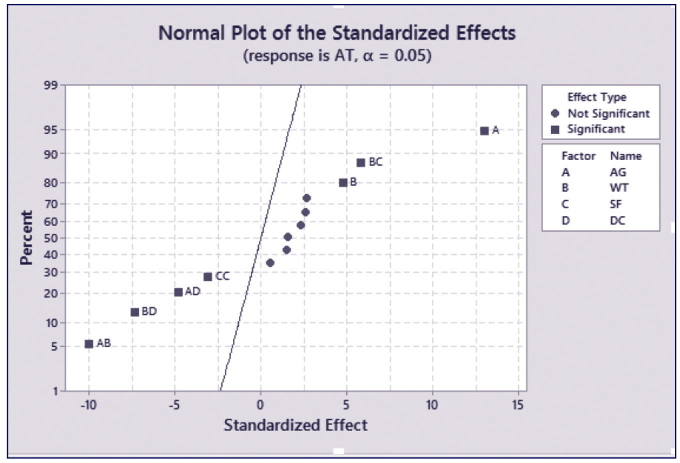

Fig. 3 (a). Normal plot of the standardized effect

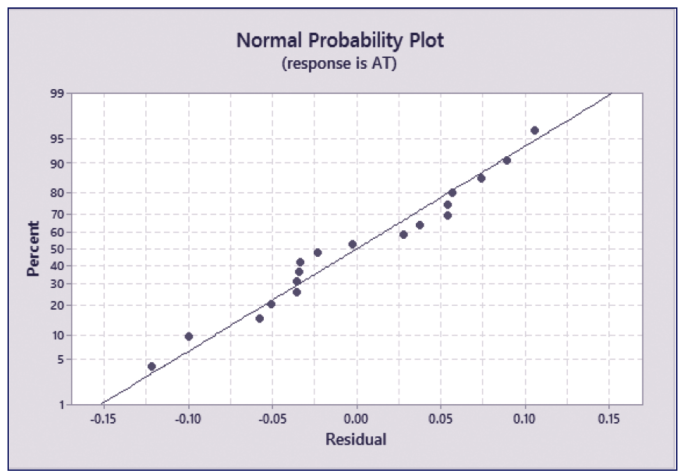

Fig. 3 (b). Normal probability

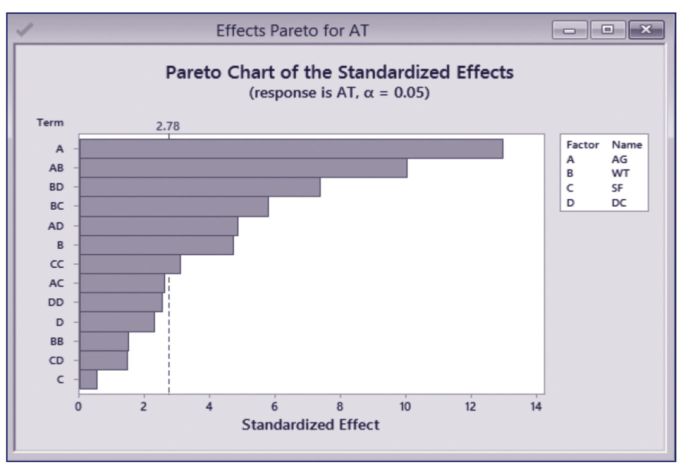

Fig. 3 (c). Pareto chart of the standardized effect.

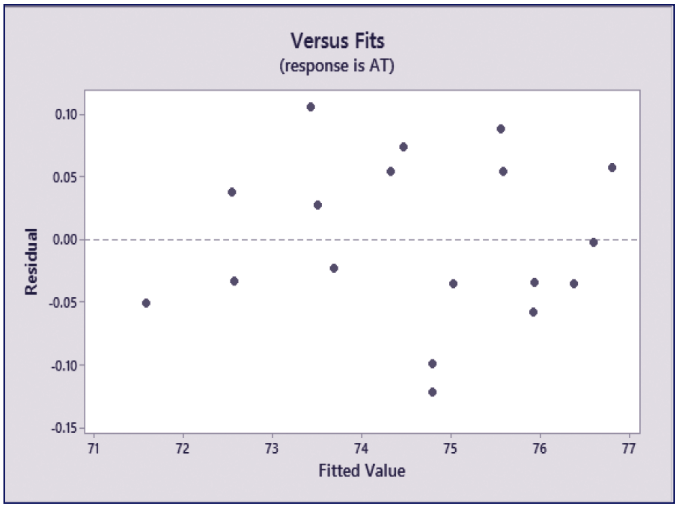

Fig. 3 (d). Fits plot.

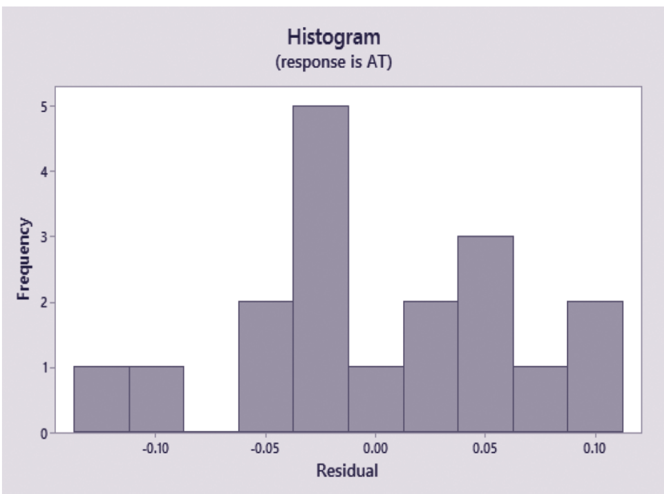

Fig. 3 (e). Histogram.

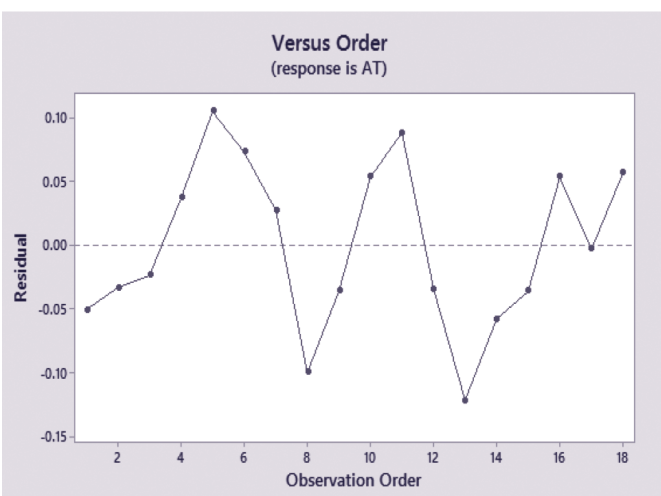

Fig. 3 (f). Residual vs observation order.

Fig. 3. Plots obtain during the data analysis through RSM.

Source	DOF	Adj. SS	ADj.MS	F-value	P-Value
Model	13	38.5863	2.96818	164.84	0.000
Linear	4	3.3891	0.84728	47.06	0.001
AG	1	3.0480	3.04795	169.27	0.000
BW	1	0.4038	0.40385	22.43	0.009
SF	1	0.0051	0.00507	0.28	0.624
DC	1	0.0963	0.09633	5.35	0.082
Square	3	0.3250	0.10833	6.02	0.058
WT^2	1	0.0409	0.04093	2.27	0.206
SF^2	1	0.1745	0.17446	9.69	0.036
DC^2	1	0.1180	0.1180	6.55	0.063
Two way interaction	6	3.7811	0.63018	35.00	0.002
AG*WT	1	1.8158	1.81584	100.85	0.001
AG*SF	1	0.1244	0.12439	6.91	0.058
AG*DC	1	0.4234	0.42344	23.52	0.0008
WT*SF	1	0.6033	0.60331	33.51	0.004
WT*DC	1	0.9832	0.98222	54.60	0.0020
SF*DC	1	0.0389	0.03889	2.16	0.216
Error	4	0.0720	0.01801		
Total	17	38.6583			
S =0.134187 Rsq :0.9981 Rsq (adj):0.9921 Rsq (pred):0.8264					

Table 4. Analysis of variance (ANOVA) to find out the impact of process parameters.

Fig 3(a-b) shows the normal plots of residuals where the error or residuals emerge on the inclined straight line. The normality test shows the formulation of good RSM model. It is a graph between % probabilities vs. residuals. The Pareto plot 3(c) shows the horizontal bar that crosses the reference line are known as a significant. The bars A (AG),AB(AG*WT),AD(AG*DC),BD(WT*DC),BC(WT*SF),B(WT) and CC(SF*SF) are significant impact on the apparent masses while AC(AG*SF), DD(DC*DC), D(DC), BB(WT*WT), CD(SF*DC)and C (SF)are not significant. Fits is the measure of model closeness w.r.t the actual response the fits plot is as shown in fig 3(d). Figure 3(e) and 3(f) error analysis in the form of histogram and the residual plots. Surface plots are the three-dimensional representation of three variables in which the response variables are plotted on Z axis while the two variables are on the X and y axis respectively. The remaining variables are kept constant at their mean value during the analysis. In other world, it is the representation of interaction effect of two variables on the response variables. From fig. 4(a), it can see that the magnitude of the response apparent masses (AM) increases with increase in the age and the weight. Figure 4(b) is the representation of AM w.r.t. the age and stiffness in the form of surface plot. It can see from the figure 4(b) that the response AM increases with increase in the age and the stiffness. From figure 4(c-f), it is observed that the response AM is increases with increase in the weight parameters and the damping coefficient while it goes on decreasing with increase in the stiffness parameters.

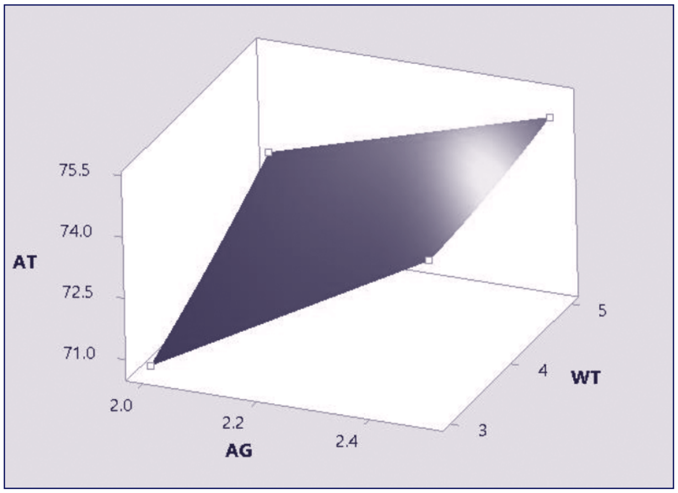

Fig. 4 (a). Surface plot of AT vs AG, WT.

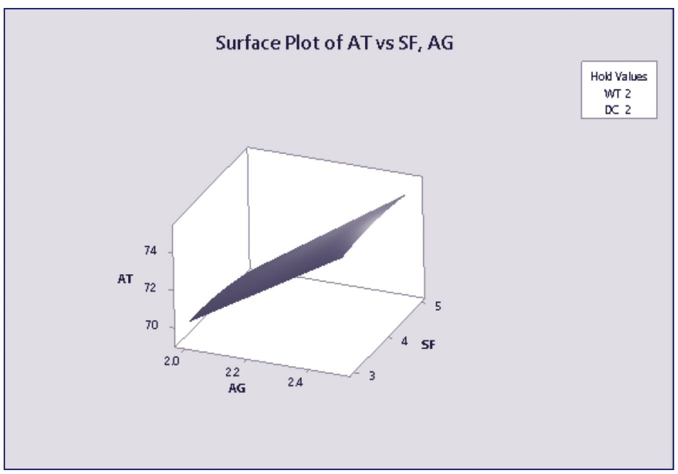

Fig. 4 (b). Surface plot of AT vs AG, SF.

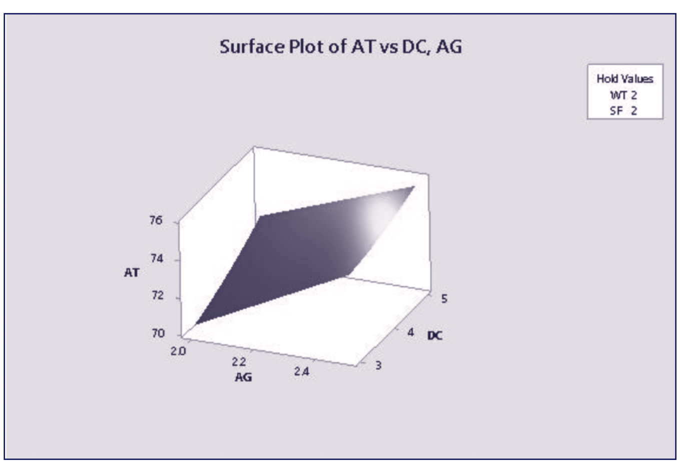

Fig. 4 (c). Surface plot of AT vs AG, DC.

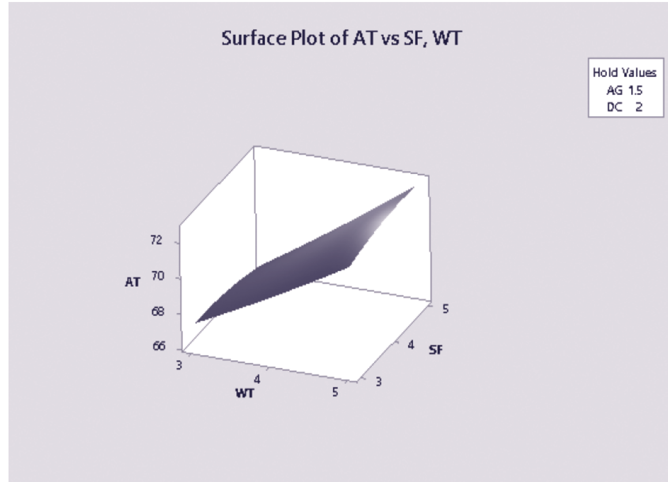

Fig. 4 (d). Surface plot of AT vs WT, SF.

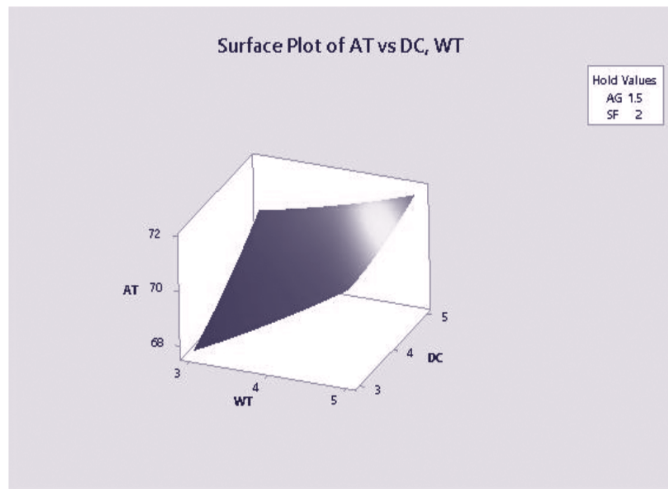

Fig. 4 (e). Surface plot of AT vs DC, WT.

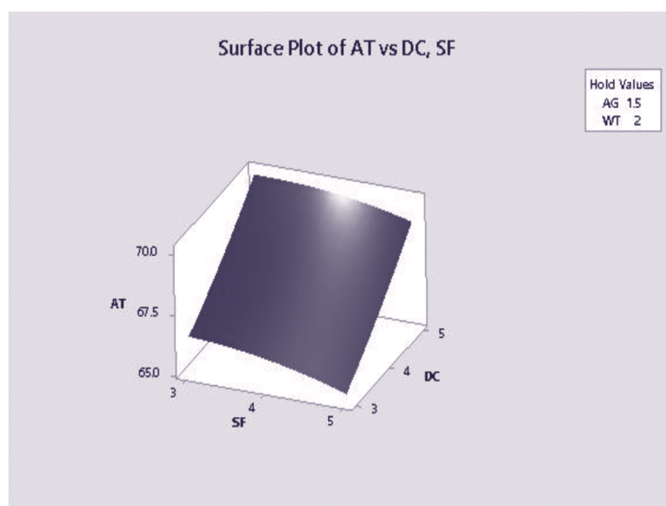

Fig. 4 (f). Surface plot of AT vs DC, SF.

Fig. 4. Surface plots obtain during the data analysis through RSM.

The contour plots are the slices along the axis or two dimensional; representations of the surface plots. The various plots are as shown in fig 5 (a-f).

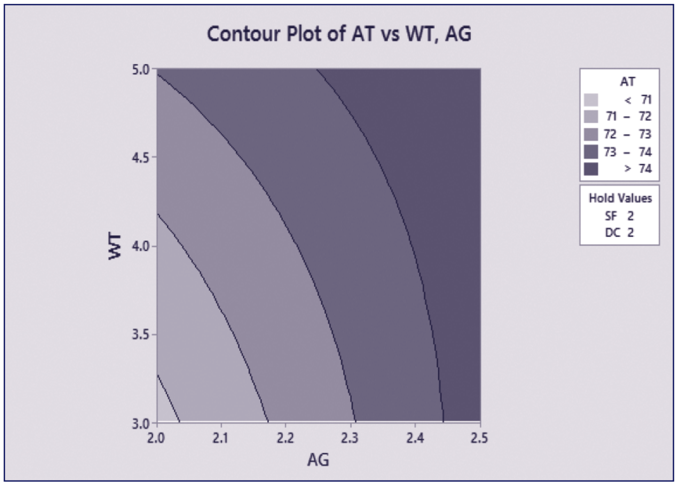

Fig. 5 (a). Contour plot of AT vs WT, AG.

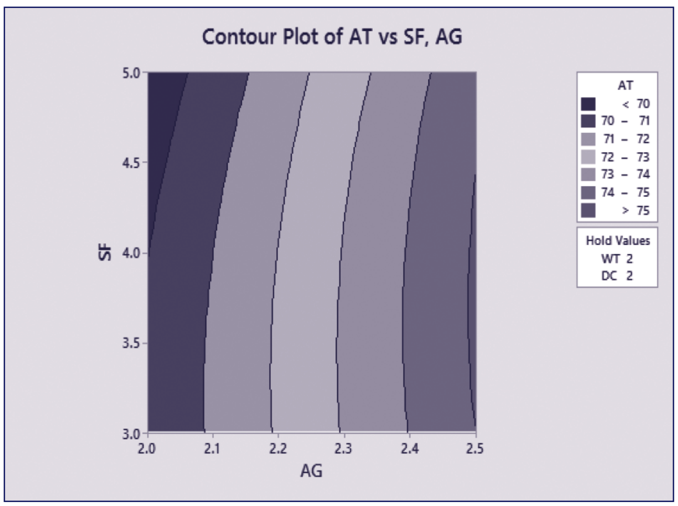

Fig. 5 (b). Contour plot of AT vs SF, AG.

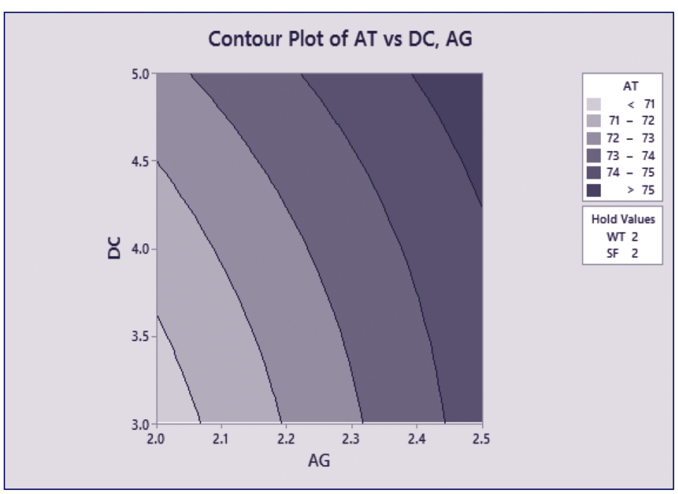

Fig. 5 (c). Contour plot of AT vs DC, AG.

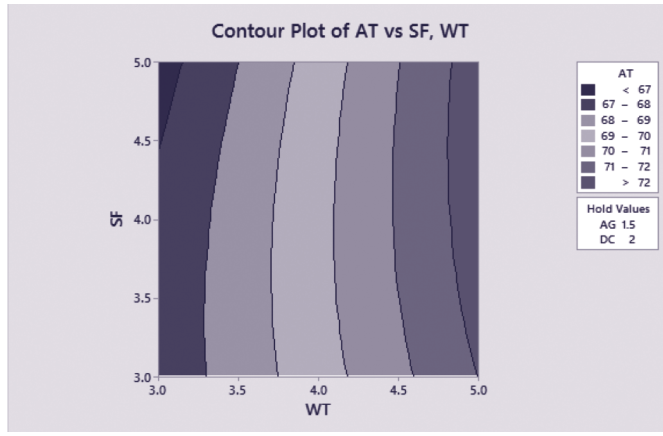

Fig. 5 (d). Contour plot of AT vs SF, WT.

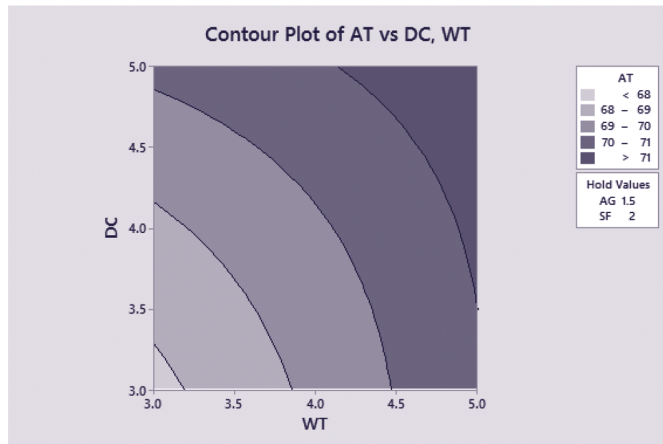

Fig. 5 (e). Contour plot of AT vs DC, WT.

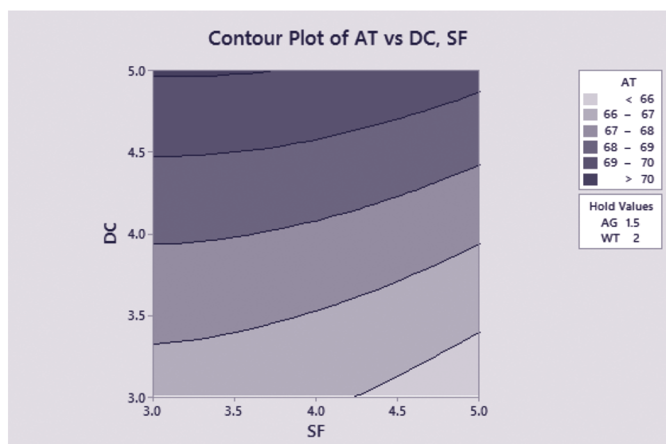

Fig. 5 (f). Contour plot of AT vs SF, DC.

Fig. 5. Contour plots obtain during the data analysis through RSM.

Analysis of variance (ANOVA) is carried out to find out the impact of various process parameters on the response (AM). The results obtained through ANOVA are tabulated in Table 4.

From the ANOVA table, it has been observed that the parameter such as the age and the body weight has a significant impact on the apparent mass. The interaction terms of variable age and weight, age and stiffness shows the significance impact on the response variable.

2.2 Optimization using Desirability function

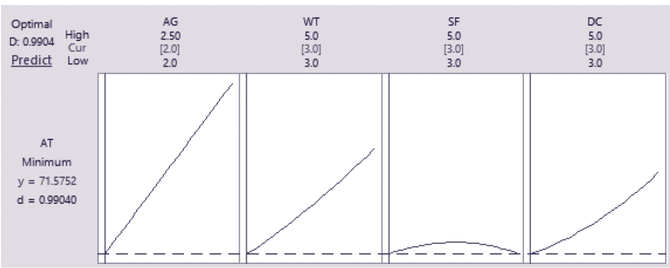

Fig. 5. Optimization Plot

Response	Goal	Lower	Target	Upper	Weight	Impor-tance
Apparent (Masses (AM	Minimum	71.524	71.524	76.8521	1	1
Solution	Parameters				Composite Desirability	
	AG	WT	SP	DC		
71.5752	2	3	3	3	0.990396	

Table 5. Analysis of variance (ANOVA) to find out the impact of process parameters.

The desirability function (DF) is a very capable approach use for the optimization of any multi-response system. The score is calculated using Equation (10).The optimize parameters are selected on the basis of maximum score. The DF analysis is carried out using following procedure.

Step 1: Calculate the individual desirability index (d_i) for the corresponding responses using the formula proposed by the Derringer and Suich [1980]. There are three forms of the desirability functions according to the response characteristics. Desirability function for "**Nominal or target is best**" If a response is of the "nominal is best" kind, then its individual desirability function is calculated using Equation (10).

$$D_i Z_i = \begin{cases} 0, & \text{if } Z_i\,(x) < LO_i \\ \left(\dfrac{Z_i\,(x) - LO_i}{TR_i - LO_i}\right)^S & \text{if } LO_i < Z_i\,(x) < TR_i \\ \left(\dfrac{Z_i\,(x) - UP_i}{TR_i - UP_i}\right)^T & \text{if } TR_i < Y_i\,(x) < UP_i \\ 0, & \text{if } Z_i\,(x) < UP_i \end{cases} \quad (10)$$

With the exponents S and ***T*** determining how important it is to hit the target value. Desirability function for maximizing a response or **larger is best** If a response is to be maximized instead, the individual desirability is defined as

$$D_i Z_i = \begin{cases} 0, & \text{if } Z_i\,(x) < LO_i \\ \left(\dfrac{Z_i\,(x) - LO_i}{TR_i - LO_i}\right)^S & \text{if } LO_i < Z_i\,(x) < TR_i \\ 0, & \text{if } Z_i\,(x) > TR_i \end{cases} \quad (11)$$

with $\mathbf{TR_i}$ in this case interpreted as a large enough value for the response. Desirability functions for minimizing a response or **smaller is the best**. We could use Equation (12).

$$D_i Z_i = \begin{cases} 1, & \text{if } Z_i\,(x) < TR_i \\ \left(\dfrac{Z_i\,(x) - UP_i}{TR_i - UP_i}\right)^S & \text{if } TR_i < Z_i\,(x) < UP_i \\ 0, & \text{if } Z_i\,(x) > UP_i \end{cases} \quad (12)$$

With $\mathbf{TR_i}$ denoting a small enough value for the response. In the present work , "Smaller is the best" for the biodynamic response (AM) is employed to determine the individual desirability values, delaminaion factor and machining force since all responses are to be minimized.

Step 2: For each response variable Z_i **(x)**, a desirability function $\mathbf{D_i (Z_i)}$ allocates statistics between 0 and 1 to the probable values of Z_i, with $\mathbf{D_i(Z_i) = 0}$ representing a totally disagreeable value of $\mathbf{Z_i}$ and $\mathbf{D_i (Z_i) = 1}$ representing a completely advantageous or perfect response value. The individual desirability's are then united using the geometric mean, which gives the overall desirability $\mathbf{D_o}$ as shown in equation 13.

$$D_o = \sqrt[W]{D_1^{w1} \times D_2^{w2} \times D_3^{w3} \times - - - - - D_Z^{wz}} \quad (13)$$

with **w** denoting the weightage of an individual response variables while W is the total of weightage assign. Let $\mathbf{LO_i}$, $\mathbf{UP_i}$ and $\mathbf{TR_i}$ be the lower, upper, and target values, respectively, that are desired for response $\mathbf{Z_i}$, with $\mathbf{LO_i \leq TR_i \geq UP_i}$.

Step 3: Finally the combination whose overall desirability (Do) is highest is selected as an optimized parameters.

Optimal combinations of parameters are determined based on assumed weight age of for response AM. As there is only one response parameter, 100 % weight age is assign to the response AM. Based on assumed weightage, the composite desirability values are also calculated and tabulated in Table 5**.** From the above analysis, It can seen that the highest value for the composite desirability score is 0.990396 corresponding to the minimum AM value as 71.5752. The optimum set of various biodynamic parameters are AG(2)-WT(3)-SP(3)-DC (3). It indicates that for optimizing the use of above design 6-DOF model (to minimize the AM value), Age of the male subject is less than 50 years, the weight is more than 70 kg, the stiffness and coefficient is at the higher level.

3. CONCLUSION

This study presented the impact of vibration on the biodynamic response measure in term of apparent masses. Six –degrees of freedom model were developed for the investigation. The parameters such as weight, age, body stiffness and the damping coefficient were considered for the investigation. The mass, stiffness and damping coefficient were calculated on the basis of anthropometric features of the male subject. Three males with the age more than 50 and less than 50 were considered for the investigation. The male subjects were selected in such as way that all the verities of the male subjects have been covered. The well-known modelling techniques i.e RSM was employed for the analysis. From the experimental findings, it has been observed that the parameters such as weight and the age of the subject were the most influencing parameters which increasing the apparent masses and created the injuries in the human body. The parameters such as damping coefficient and the body stiffness have adversely affected the apparent masses. The present work will help the automobile industries to design the moving vehicle chair to minimize the apparent masses. It also helps to minimize the injuries created due to the bad seating posture. The presented work is the novel approach in two ways. The presented 6-DOF biodynamic model is a novel model developed for analysing the human seated posture. No researcher has tried 6-DOF model for effectively study the human seated posture. No researcher has tried the RSM approach to analyse the human biodynamic models.

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