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Analytical Analysis and Numerical Prediction of Seven DOF Human Vibratory Model for the Various Cars Driving Posture

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Abstract*—Vibration has become an important consideration in engineering. Development of industries and vehicles make the subject even more important. In today's world every family has a car therefore it become essential to study the phenomenon of vehicle vibration and its effects on humans. In vehicle system occupational drivers might expose themselves to vibration for the long time. This may cause illness of the spine such as chronic lumbago or low back pain [7]. Therefore, it is necessary to evaluate the influence of vibration to spinal column and to make appropriate guidelines or counter plans. In ISO 2631 assessment of vibration effects to human in the view of adverse health effect was already presented. However, it is necessary to carry out further research to understand the effect of vibration to the human body to examine their validity and to prepare for the future revision. This paper shows the detail measurement of human response to vibration, and the modeling of the seated human body for the assessment of vibration risk. The vibration transmissibility's from the seat surface to the spinal column and to the head is measured during the exposure to the vertical excitation. A simplified model having 7 DOF is constructed so that transmissibility's of the model fit to those of experiment. In the present paper, vehicle vibration analyses are carried out. For this analysis it was proposed to perform the vibration tests for different vehicle models. Vibration data for each model at three different conditions which are road, speed and tyre infiltration conditions were taken by using fast Fourier transform (FFT). The spectrum obtained is used for further analysis for determining acceleration levels at different frequencies. By referring ISO 2631[6], Human comfort chart, the comment is made regarding the acceleration level. Mostly lower frequencies of vibration of vibration raging from 0 to 80 Hz are affecting in Human body

This paper focus on literature review of Human body vibration proposes a herustic or a new approach to analyses impact of vibration on driver seating posture.

***Index Terms*—: Human Body Vibration Analyses, Anthropometric Data.**

I. INTRODUCTION

Human body vibration is phenomenon affecting millions of workers in the world. Among this are light and heavy equipment operators, Machine tool Operators and Truck Drivers. Many harmful side effect of the vibration can be both physiological and neurological which in many cases lead to permanent injury. High speed vehicles frequently transmit dynamic forces to their occupants. Depending upon the intensity and duration of such a disturbances, serious impairment of operator or passenger functioning may occur. These problems have lead to extensive research directed towards defining and understanding the dynamics of the human body other endeavors such as health and medical studies and even athletic interest have also created a desire for comprehensive human dynamic analysis. One approach to the understand the human body vibration is through mathematical model. Mathematical Modeling is an expectable tool in engineering and many areas of the physical sciences. If the model can be shown to be reliable, it is an effective, economical and versatile method of studying the response of the system due to a wide variety of input conditions. The human body obviously consist of multitudes of inter connected masses, springs and dampers and should therefore behave as a dynamic system with many degree of freedom. One approach to understand the human body vibration is via a suitably formulated mathematical model that duplicates measured human body frequency responses [1].

The identification of mathematical model for a structural system entails the identification of mass, stiffness and damping matrices that consistently predict the dynamic responses of the structure, which are responsible for responses measured under operating conditions. While there are a variety of rational techniques, the method obtaining the damping matrix has not achieved a comparable level of confidence in human body vibration. The difficulty is because the damping mechanism in real structure is not quite readily model from a simple physical description of structure. In fact realistic estimates occurring in a vibrating structure are obtainable only from experimental measurement. This work takes a small step forward by considering human body as a combination of a spring and dampers. This thesis presents the formulation of human body model [5].

II. PROPOSED METHODOLOGY

A. *Preparation 7 DOF Model*

Steps for 7 DOF Model development [1].

1. Segmentation of the body.
2. The Evaluation of mass, stiffness and damping value.
3. Lumping the segments at discrete point & connecting them through mass less spring.
4. Evaluation of the stiffness of the connecting spring of the model via stiffness values of the individual segments.

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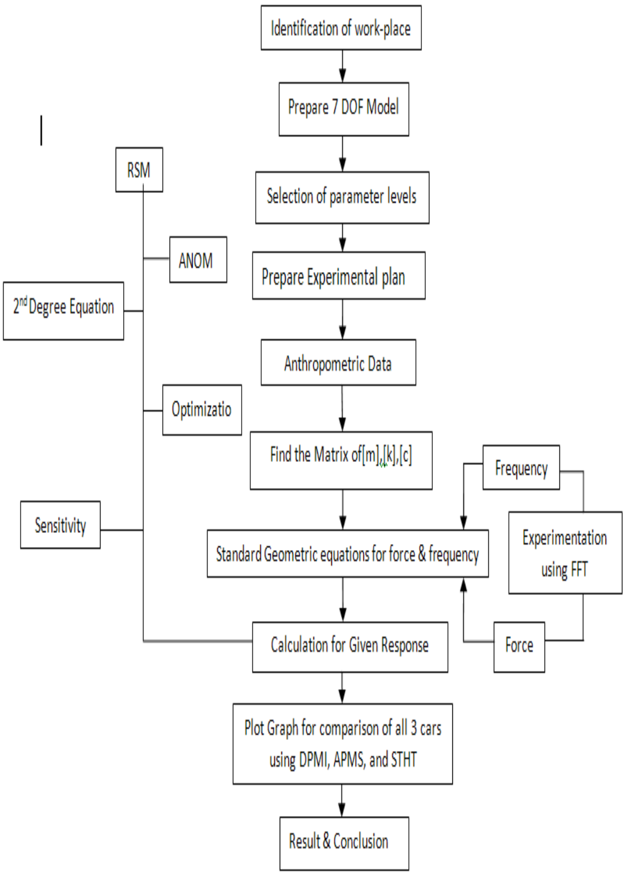

Fig.1.Proposed Methodology

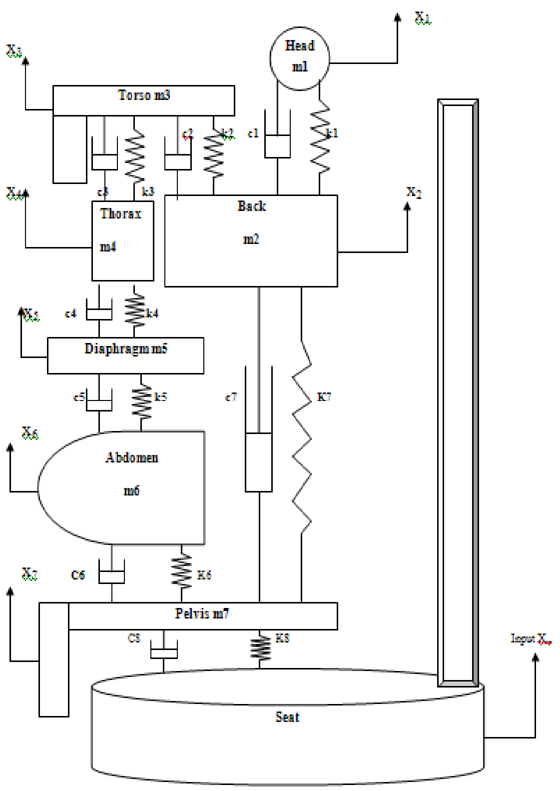

Fig.: Human Body Sitting Posture 7-DOF vibratory Model

Fig.2.Human Body Sitting posture 7-DOF vibratory Model

B. Identification of parameters

Parameters Levels:

Code	1	2	3
Speed (Km/Hr)	Slow	Medium	High
Road Profile	Poor Surface (P)	Rough (R)	Smooth (S)
Air in the all 4 wheels	Min(L)	Average (M)	Max(H)

Code	1	2	3
Speed (Km/Hr)	20	40	60
Road Profile	0.5	0.75	1
Air in the all 4 wheels	25	30	35

Table.1.Parameter selection

C. Experimental plan for above parameters

The experimental design is widely used in various fields. The Fractional designs are effective when the number of factors considered is large and when it is difficult to experiment all the combinations. It is effective to use the orthogonal arrays in factorial designs. Three level orthogonal arrays such as $L_9$and L_{27} are used when the factors of three levels are considered.

In the factorial experiment, it is necessary to experiment by combining the levels of the factors taken up all. The total experiment frequency increases rapidly when the number of factors increases, and the inconvenience in the experiment is caused .For our case the orthogonal array experiment that is the method of not the experiment on all level combination but conducting only part of the experiment is useful, which gives us 94% realistic answers in our experimental plan.

CAR 1/2/3								
RUN	Speed	Road Profile	Air in the Rear Wheel	Exciting Frequency HZ	Acc"	Vel.	Displacement	Force
1	1	1	1	-	-	-	-	-
2	1	1	1	-	-	-	-	-
3	1	1	1	-	-	-	-	-
4	1	2	2	-	-	-	-	-
5	1	2	2	-	-	-	-	-
6	1	2	2	-	-	-	-	-
7	1	3	3	-	-	-	-	-
8	1	3	3	-	-	-	-	-
9	1	3	3	-	-	-	-	-
10	2	1	2	-	-	-	-	-
11	2	1	2	-	-	-	-	-
12	2	1	2	-	-	-	-	-
13	2	2	3	-	-	-	-	-
14	2	2	3	-	-	-	-	-
15	2	2	3	-	-	-	-	-
16	2	3	1	-	-	-	-	-
17	2	3	1	-	-	-	-	-
18	2	3	1	-	-	-	-	-
19	3	1	3	-	-	-	-	-
20	3	1	3	-	-	-	-	-
21	3	1	3	-	-	-	-	-
22	3	2	1	-	-	-	-	-
23	3	2	1	-	-	-	-	-
24	3	2	1	-	-	-	-	-
25	3	3	2	-	-	-	-	-
26	3	3	2	-	-	-	-	-
27	3	3	2	-	-	-	-	-

Table.2.Experimental plan on selected parameters

Prepare experimental plan for above parameter levels [table 1.] Using Taguchi L -27 orthogonal array. Keeping time span constant as 30sec for each run of all three cars [3].

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- Taguchi Orthogonal array Design: L27(3X3)
- Factors: 3(Parameters)

Runs: 27

III. EVALUATION OF ANTHROPOMETRIC DATA

Anthropometric Data For Car Driver			
S.N.	**Parameters**	**Notation**	**Dimensions in (cm)**
1	Standing Height	**L1**	-
2	Shoulder Height	**L2**	-
3	Armpit Height	**L3**	-
4	Waist Height	**L4**	-
5	Seated Height	**L5**	-
6	Head length	**L6**	-
7	Head Breadth	**L7**	-
8	Head to Chin Height	**L8**	-
9	Neck Circumference	**L9**	-
10	Shoulder Breadth	**L10**	-
11	Chest Depth	**L11**	-
12	Chest Breadth	**L12**	-
13	Waist Depth	**L13**	-
14	Waist Breadth	**L14**	-
15	Buttock Depth	**L15**	-
16	Hip Breadth, Standing	**L16**	-
17	Shoulder to Elbow Length	**L17**	-
18	Forearm -Hand Length	**L18**	-
19	Biceps Circumference	**L19**	-
20	Elbow Circumference	**L20**	-
21	Forearm Circumference	**L21**	-
22	Wrist Circumference	**L22**	-
23	Knee Height, seated	**L23**	-
24	Thigh Circumference	**L24**	-
25	Upper Leg Circumference	**L25**	-
26	Knee Circumference	**L26**	-
27	Calf Circumference	**L27**	-
28	Ankle Circumference	**L28**	-
29	Ankle Height Outside	**L29**	-
30	Foot Breadth	**L30**	-
31	Foot Length	**L31**	-
32	Weight	-	-

Table.3.Measurements of Anthropometric Data for car driver sitting posture

All dimension for anthropometric data is taken for average Indians.

Extensive modeling efforts have been made in the area of biomechanics based on anthropometric analysis. In order to study human body vibration, it is essential to formulate a mathematical model that duplicates the actual system. The inherent advantage of this approach is that the model parameters can be varied for analysis purpose. A properly matched model would indicate the source of measured human body characteristics such as resonance peaks that would be difficult to determine directly. [4, 5]

Studying various papers available in the literature, many mathematical models to duplicate the human body vibration responses are found. But we choose seven dof model for our experimentation.

A. Statistical dimensions of epicycloids representing body segments

Following formulas are used from Biomechanics references to calculate the various Body Segments.

S.N	Body Segment	Mass Element	Formulae		
			ai	bi	ci
1	Head (H)	**M1**	L7/2	L7/2	L6/2
2	Neck (N)	**M2**	L8/2π	L8/2π	(L1-L2-L6)/2
3	Upper Torso (UT)	**M3**	L12/2	L11/2	L17/2
4	Central Torso (CT)	**M8**	L14/2	L13/2	(L17+L18)/4
5	Lower Torso (LT)	**M9**	L16/4	L15/2	L18/4
6	Upper Arms (RUA,LUA)	**M4,M5**	L19/2π	L19/2π	L19/2
7	Lower Arms (RLA,LLA)	**M6,M7**	L21/2π	L21/2π	L18/2
8	Upper Legs (RUL,LUL)	**M10,M11**	**L25/2π**	**(L23-L29+L25/2π)/2**	**L25/2π**
9	Lower Legs (RLL,LLL)	**M12,M13**	L27/2π	L27/2π	(L23-L29)/2
10	Feet (RF,LF)	**M14,M15**	L30/2	L31/2	L29/2

Table.4.Relation between Mass and Anthropometric data

B. Calculation for modulus of elasticity (e) of human body material:

$E=E_b\ V_b+ E_t\ V_t$ -------------------- (eqn 1)

Where,

Eb= Modulus of elasticity for bones.

Et= Modulus of elasticity for tissues.

Vb= Volume fraction of bone.

Vt= Volume fraction of tissue.

Eb= $2.26*10^{11}$ dyen/cm^2 (In S.I unit 2.6 kN/ m^2).

Et=$7.5*10^9$ dyne/ cm^2 (In S.I unit 7.5 kN/ m^2).

Volume fraction of bone and tissue changes from segment to segment, moreover it changes from one posture to another. Because of non availability of these data following empirical relation is used

.

$E= \sqrt[5]{Eb * Et^2}$------------------------ (eqn 2)

E=1.08 MN/m^2

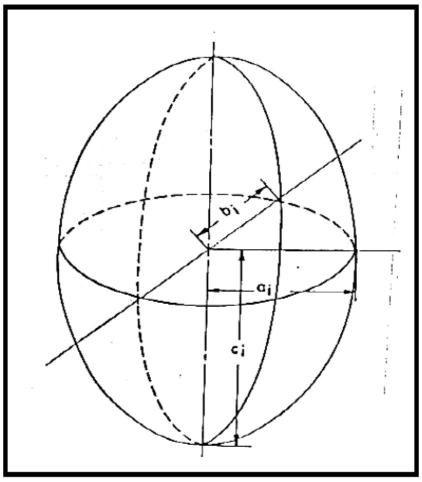

Fig.2. Numerical Parameter

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C. Evaluation of mass of the segments

Though a human body is in reality not a homogeneous mass, the bulk (average) densities of different body segments are nearly the same as shown in Table , which is taken from reference [Bartz A. J., Gianotti.C.R, .*Computer Program to Generate Dimensional and Inertial Properties of the Human Body*., Journal of Engineering for Industry, Vol.97, pp.49-57, (1975)]

In a geometrical model each body segment is represented by mean of ellipsoids whose dimensions are known from Table. Now if it is assumed that weights of all these ellipsoids are proportional to their volumes because specific gravity does not very much, Table, the percentage weight of these segments can be fixed up in respect of total body weight.

S.N.	Segment	Specific Gravity
1	Head, Neck	1.111
2	Upper Torso, Central Torso	1.031
3	Upper arm	1.081
4	Lower arm	1.122
5	Upper leg	1.069
6	Lower leg	1.095
7	Foot	1.100

Table.5. Average Body Segment Specific Gravity

The densities of each segment are therefore taken to be the same and equal to the average density of the whole body. Therefore the mass of an i^{th} segment may be expressed as.

Where,

- V_i = Volume of the i^{th} Segment = $\Pi * a_i * b_i * c_i$
- M = Total body mass.
- n = Total number of body Segments.
- $a_i * b_i * c_i$ are the semi axes of the ellipsoid.
- Mi = the mass of that particular segment.

Driver									
Calculation for Mass and Stiffness for all the Segments									
S.N	Body Segment	Mass Element	Formulae			Volume of Segments	Mass	Mass
			ai	bi	ci			
1	Head (H)	M1	.	.	.	.	M1	.
2	Neck (N)	M2	.	.	.	.	M2	.
3	Upper Torso (UT)	M3	.	.	.	.	M3	.
4	Central Torso (CT)	M8	.	.	.	.	M8	.
5	Lower Torso (LT)	M9	.	.	.	.	M9	.
6	Upper Arms (RUA,LUA)	M4,M5	.	.	.	.	M4,M5	.
7	Lower Arms (RLA,LLA)	M6,M7	.	.	.	.	M6,M7	.
8	Upper Legs (RUL,LUL)	M10,M11	.	.	.	.	M10,M11	.
9	Lower Legs (RLL,LLL)	M12,M13	.	.	.	.	M12,M13	.
10	Feet (RF,LF)	M14,M15	.	.	.	.	M14,M15	.

Table.6. Calculation of mass and stiffness for all segments

The system equations of motion, equation, for the model can be expressed in matrix form as follows:

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=\{f\}$$

-------------------------(3)

Where [M], [C] and [K} are mass, damping, and stiffness matrices, respectively; [f] is the force vector due to external excitation.

General Mass Matrix:

$$[M]=\begin{matrix} m1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & m2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & m3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & m4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & m6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & m7 \end{matrix}$$

General Stiffness Matrix:

$$[K]=\begin{matrix} k1 & -k1 & 0 & 0 & 0 & 0 & 0 \\ -k1 & k1+k7+k2 & -k2 & 0 & 0 & 0 & -k7 \\ 0 & -k2 & k2+k3 & -k3 & 0 & 0 & 0 \\ 0 & 0 & -k3 & k3+k4 & -k5 & 0 & 0 \\ 0 & 0 & 0 & -k4 & k4+k5 & -k5 & 0 \\ 0 & 0 & 0 & 0 & -k5 & k5+k6 & -k6 \\ 0 & -k7 & 0 & 0 & 0 & -k6 & k6+k8 \end{matrix}$$

General Damping Coefficient Matrix:

$$[C]=\begin{matrix} c1 & -c1 & 0 & 0 & 0 & 0 & 0 \\ -c1 & c1+c7+c2 & -c2 & 0 & 0 & 0 & -c7 \\ 0 & -c2 & c2+c3 & -c3 & 0 & 0 & 0 \\ 0 & 0 & -c3 & c3+c4 & -c5 & 0 & 0 \\ 0 & 0 & 0 & -c4 & c4+c5 & -c5 & 0 \\ 0 & 0 & 0 & 0 & -c5 & c5+c6 & -c6 \\ 0 & -c7 & 0 & 0 & 0 & -c6 & c6+c8 \end{matrix}$$

General Force Matrix:-

$$[f]=\begin{matrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ c7\dot{X}_{se}+k7X_{se} \end{matrix}$$

By taking the Fourier transformation of equation (1) the following matrix form of equation can be obtained:

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$$\{X(j\omega)\} = \{[K] - \omega^2[M] + jw[C]\}^{-1}\{F(j\omega)\}$$

Where,
{X(jω)} and {F(jω)} are the complex Fourier transformation vectors of {x} and {f} respectively.

IV. RESPONSE MEASURE FOR THE HUMAN BODY

The biodynamic response of a seated human body exposed to whole-body vibration can be broadly categorized into two types. The first category "To the- body" force motion interrelation as a function of frequency at the human-seat interface, expressed as the driving-point mechanical impedance (DPMI) or the apparent mass (APMS). The second category "Through-the-body" response function, generally termed as seat-to-head transmissibility (STHT) for the seated occupant [2].

1. **DPMI** :The DPMI relates the driving force and resulting velocity response at the driving point (the seat-buttocks interface), and is given by,

$$Z(j\omega) = F(j\omega) \;/\; V(j\omega)$$

Where,
Z(jω) is the complex DPMI,
F(jω) & V(jω) are the driving force and response velocity at the driving point,
ω is the angular frequency in rad/ sec.
Accordingly,
DPMI for the model can be represented as:

$$\{DPMI(j\omega)\} = \left| (c4 + \frac{k4}{j\omega})(\frac{X_4(j\omega)}{X_0(\omega)}) - (c4 + \frac{k4}{j\omega}) \right|$$

In a similar manner, the apparent mass response relates the driving force to the resulting acceleration response, and is given by

2. APMS:

$$\{APMS(j\omega)\} = \frac{F(j\omega)}{a(j\omega)}$$

Where,
a(jω) is the acceleration response at the driving point.

The magnitude of APMS offers a simple physical interpretation as it is equal to the static mass of the human body supported by the seat at very low frequencies, when the human body resembles that of a rigid mass. The above two functions are frequently used interchangeably, due to their direct relationship that given by:

$$\{APMS(j\omega)\} = \frac{DPMI(j\omega)}{j\omega}$$

APMS for the model can be represented as:

$$\{APMS(j\omega)\} = \left| (\frac{c4}{j\omega} + \frac{k4}{-\omega^2})(\frac{X_4(j\omega)}{X_0(\omega)}) - (\frac{c4}{j\omega} + \frac{k4}{-\omega^2}) \right|$$

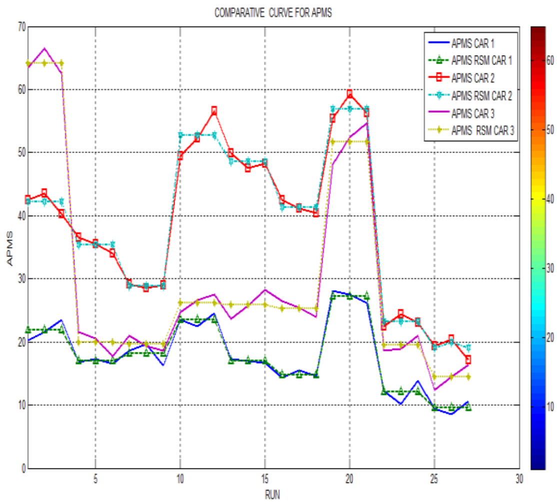
The biodynamic response characteristics of seated occupants exposed to whole body vibration can also be expressed in terms of seat-to-head transmissibility (STHT), which is termed as "through-the-body" response function. Unlike the force-motion relationship at the driving-point, the STHT function describes the transmission of vibration through the seated body.

The STHT response function is expressed as:

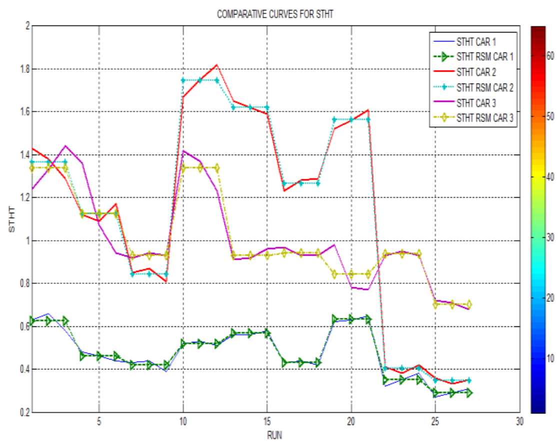
3. STHT

$$\{STHT(j\omega)\} = \frac{X_1(j\omega)}{X_0(j\omega)}$$

Graph.1.DPMI



Graph.2.APMS



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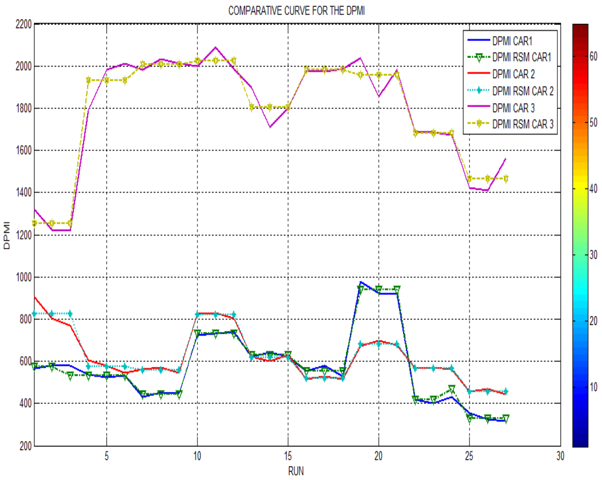

Graph.3.STHT

V.CONCLUSION

This present paper the experimentation is carried out to study effect of vehicle vibration on humans through vibration analysis and feasibility of it, practically investigated. Experimental and analytical studies conducted on the human body suggest that whole body vibration can cause spinal injury which results in low bag pain. However the most important objective is to analyze and find procedure and method to minimize the effect of vibration on the human body based on such model.

The objective of the present work was to develop a generalized approach towards human body vibratory modeling including spring, mass and damping considerations. For finding best optimum condition which creates minimum vibration in human body for finding that we use response surface method. It become extension of this work it will give us best set parameters vehicle driving which creates minimum vibration in human body which is our final objective.

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