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INVESTIGATION OF THE EFFECT OF CAR SUSPENSION PARAMETERS ON RIDE COMFORT

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ABSTRACT

The main function of suspension system in a passenger car is to provide good level of isolation from vibrations, induced because of variety of sources like road irregularities, vibrations from engine and drive line and unbalance wheels etc. In this paper an attempt is being made to investigate the effect of suspension and seat parameters on the ride comfort of a car occupant. Ride comfort is evaluated in accordance with the guide lines of ISO-2631 standards. Bond graph methodology is used to evaluate the acceleration at seat-passenger interface using quarter car model.

I. INTRODUCTION

Ride comfort, safety and handling are identified as the most important factors to be considered while evaluating the performance of the vehicle and has always been a critical topic for automobile designers, engineers and researchers. One of the most important reason that affects the customer decision and satisfaction is the level of comfort a passenger experiences while driving.The primary function of the suspension system of any vehicle is to isolate the passengers from vibrations induced due road irregularity, engine vibration or due to unbalanced vehicle wheel assembly [1]. Suspension system plays an important affecting the ride comfort of a vehicle.In current time the vehicle manufacturers are under constant pressure to provide more comfortable vehicle. The development of computing facilities in the last few decades paves the ways to use simulation-based approaches in vehicle design instead of costly and time-consuming prototype manufacturing [2].

In past few decades, a large number ofresearches have been conducted using different simulation tools to study the vehicle ride characteristics.A simulation model was proposed by Karen et. al.to predict the ride comfort using full car model. It was reported that engine vibrations also affect the comfort significantly [3].Darsivan [4] have presented a half car model to evaluate the response of the car considering the non-linear behaviour of the damper. The nonlinearity of the damper is due to the power law damper model fixed at both the front and rear end. Two models were used, and the results exposed that the vertical and pitch responses in case of bilinear damper model overestimates the responses when compared with non-linear damper model. Ata and oyadiji [5] have investigated the effect of suspension setting and configurations on performance of tracked vehicle on bumps terrains. The optimization is attempted using mixed objective functions for differentdamper position under diversifiedroad conditions at various speeds. Rakheja et. al. [6] have presented a theoretical as well as experimental study to examine the driver seat suspension system.Marzbanrad et. al. [7] have optimized the suspension system of an automobile to increase the ride comfort using design of experiment techniques. It was found that the optimal suspension setting for given range of vehicle speed and given road condition also improves the comfort at other speeds also. The comfort in an automobile is most sensitive to rear spring.

The present paper aims to investigate the affect of suspension setting on the ride comfort of a passenger car through bond graph methodology.Response surface methodology (RSM) is beingused to establish a mathematical model between suspension parameters and passenger comfort.The mathematical model so obtained is used to analyse the effect of suspension and seat variables on ride comfort.

II. BOND GRAPH MODELLING OF PASSENGER CAR

A vehicle is made up of number of components joined together through suspension systems. Figure 1 illustrates the quarter car model along with seat used in the present study. The model consists of a passenger seat, quarter sprung mass and unsprung mass (wheelset assembly).The passenger seat, sprung mass and unsprung mass are all considered rigid and are defined by their masscharacteristics.The seat is connected with the sprung mass through flexible model as spring damper combination with stiffness and damping as K_p and C_p respectively. The tire flexibility is modeled by a spring having stiffness K_t. The corresponding bond graph of the quarter car is shown in Figure 2.The simulation parameters are given in table 1. The corresponding bond graph of the quarter car is shown in Figure 2.The equation representing the bump is given by Eq. 1. The input to the model is found by differentiating Eq. 1.

$$y = \begin{cases} H \times \sin\left(\frac{\pi V t}{L}\right) \; fro \;\; 0 \leq t \leq \frac{L}{V} \\ 0 \qquad\qquad\qquad for \; t > \frac{L}{V} \end{cases} \tag{1}$$

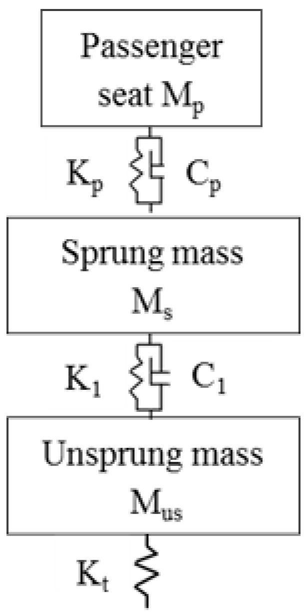

Figure 1: Quarter car model

Table 1: Simulation Parameters

S. No.	**Parameter**	**Nomenclature**	**Values**
1.	Mass of passenger seat	M_P	100 kg
2.	Quarter Sprung Mass	M_s	540 kg
3.	Unsprung mass	M_{us}	85 kg
4.	Passenger seat stiffness range	K_P	90000-120000 N/m
5.	Passenger seat damping range	C_P	400-900 N-s/m
6.	Suspension stiffness range	K1	75000-100000 N/m
7.	Suspension damping range	C1	900-3000 N-s/m
8.	Tire stiffness	K_t	2 x 10^4N/m

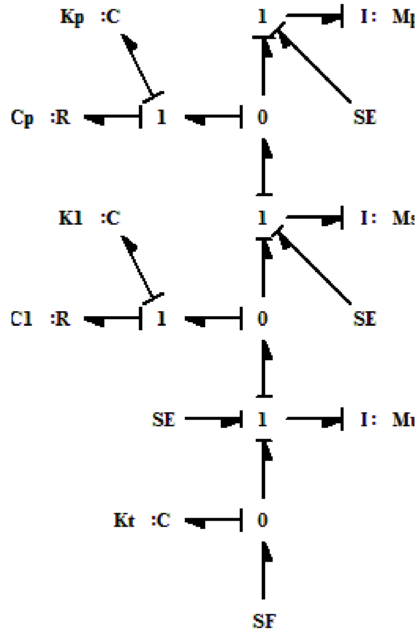

Figure 2: Bond graph model

III. RIDE COMFORT MEASUREMENT

ISO 2631-1defines methods for the measurement of periodic, random and transient whole-body vibration.The effect of vibration on human comfort and health as per ISO 2631 shall involve measurements of the weighted rms acceleration in accordance with the relation given by Eq. 2[8].

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{1/2} \tag{2}$$

where,$a_w(t)$ = is the weighted acceleration(m/s^2) and T is measurement time in sec.

IV. DESIGN LAYOUT

In present paper simulation layout obtained by response surface methodology based on central composite face centered cubic design is being applied to study the effect of seat flexibility andsuspension parameters on ride comfort. Use of CCD of RSM cuts the number of simulation runs to 30 (2^4+2x4+6) with 6 replications.As one gets the same reponse in case of computer experimentation, actual number of runs decreases to 25. The response data obtained through simulation of bond graph model as per the design layout is given in **Error! Reference source not found.**.

Table 2: Design layout with simulation result

Run	A:Kp N/m	B:Cp N-s/m	C:K1 N/m	D:C1 N-s/m	a_{rms} m/s^2
1	105000	650	87500	1950	0.6737
2	105000	650	87500	900	0.6728
3	90000	650	87500	1950	0.6261
4	90000	400	75000	900	0.6175
5	120000	400	100000	900	0.7853

6	120000	650	87500	1950	0.6976
7	120000	900	100000	3000	0.7099
8	90000	900	75000	3000	0.5981
9	105000	900	87500	1950	0.6437
10	90000	400	100000	900	0.6896
11	120000	900	75000	900	0.6411
12	90000	400	75000	3000	0.6419
13	105000	650	75000	1950	0.6370
14	105000	650	87500	1950	0.6371
15	90000	900	100000	3000	0.6355
16	120000	400	75000	3000	0.7302
17	90000	900	75000	900	0.5588
18	105000	650	87500	1950	0.6601
19	105000	650	87500	3000	0.6912
20	105000	400	87500	1950	0.7132
21	120000	400	100000	3000	0.7623
22	105000	650	87500	1950	0.6689
23	90000	900	100000	900	0.6301
24	120000	900	100000	900	0.7008
25	105000	650	87500	1950	0.6689
26	120000	400	75000	900	0.6765
27	105000	650	87500	1950	0.6689
28	90000	400	100000	3000	0.6693
29	120000	900	75000	3000	0.6567
30	105000	650	100000	1950	0.6676

V. RIDE COMFORT PREDICTION MODEL

The ride comfort prediction model is made using face cantered central composite design of RSM. Weighted root mean square acceleration (a_{rms}) obtained through simulation are fed to the Design Expert 11.0.5.0 software for further analysis. ANOVA is usually used to observe the significance of the regression model, significance of individual term and lack-of-fit of the model. The ANOVA table for ride comfort is presented in Table 3.The quadratic model for root mean square acceleration (a_{rms}) in terms of coded factors is given by Eq 3.

a_{rms}= 0.668 +0.039 A-0.0284 B+ 0.0273757 C + 0.00682032D -0.0101CD (3)

Table 3: Analysis of variance for ride comfort

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0572	5	0.0114	69.96	< 0.0001	significant
A-Kp	0.0267	1	0.0267	163.46	< 0.0001	
B-Cp	0.0145	1	0.0145	88.73	< 0.0001	

C-K1	0.0135	1	0.0135	82.48	< 0.0001	
D-C1	0.0008	1	0.0008	5.12	0.0330	
CD	0.0016	1	0.0016	10.01	0.0042	
Residual	0.0039	24	0.0002			
Lack of Fit	0.0030	19	0.0002	0.9140	0.6043	not significant
Pure Error	0.0009	5	0.0002			
Cor Total	0.0611	29				

P-valuesless than 0.0500 for the model as well as for the terms A (K_p), B (C_p), C (K_1),D (C_1) and interaction term CD ($K1C_1$)shows that the model is significant, and these terms have significant contribution in the model. Other insignificant terms are removed from the model by using forward elimination method.The normal probability plot of residuals is shown in Figure 3.One can observe from the plot that almost all the points are lying on the straight line, indicating normal distribution of the residuals.

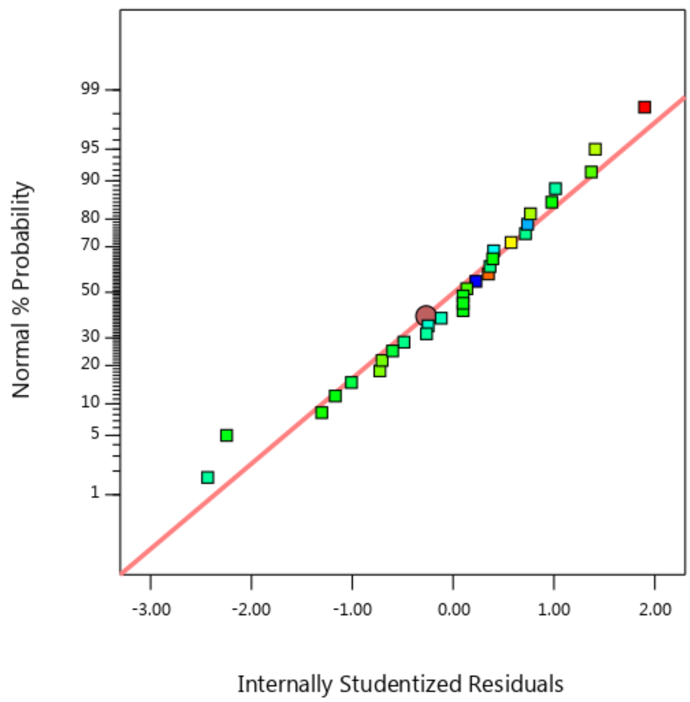

Figure 3: Normal probability plot

Figure 4presents the interaction between seat suspension spring (K_p) and car damper (C_1) keeping all other factors constant.Figure 4 revealed that the a_{rms}value increases i.e. ride comfort decreases withrise in seat stiffness and car damping.Figure 5 shows the interaction plot of car suspension spring (K_1) and car damper (C_1) for other parameters to be constant. From the plot it is clear one feel comfortable for low value of K_1 and C_1. The three-dimensional (3D) surface plots for root mean square vertical acceleration a_{rms} (ride comfort) at constant value of K_1 87500 N/m and C_1 1958 N-s/m is shown in Figures 6. From the figure, it is clear that withincrease in seat damping rms acceleration decreases i.e. comfort increases, on the contrary comfort decreases with rise in seat stiffness.

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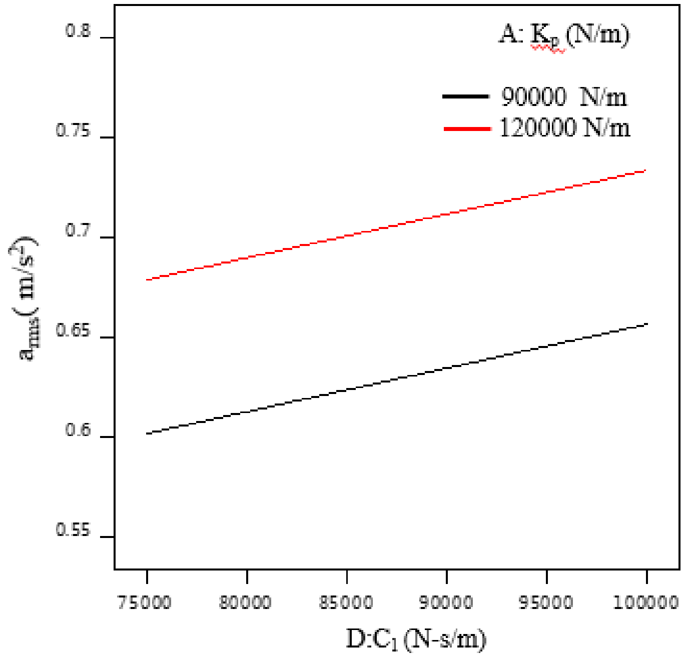

Figure 4: Interaction plot between seat suspension spring (K_p)and car damper (C_1) at C_p 650 N-s/m and K_1 87500 N/m

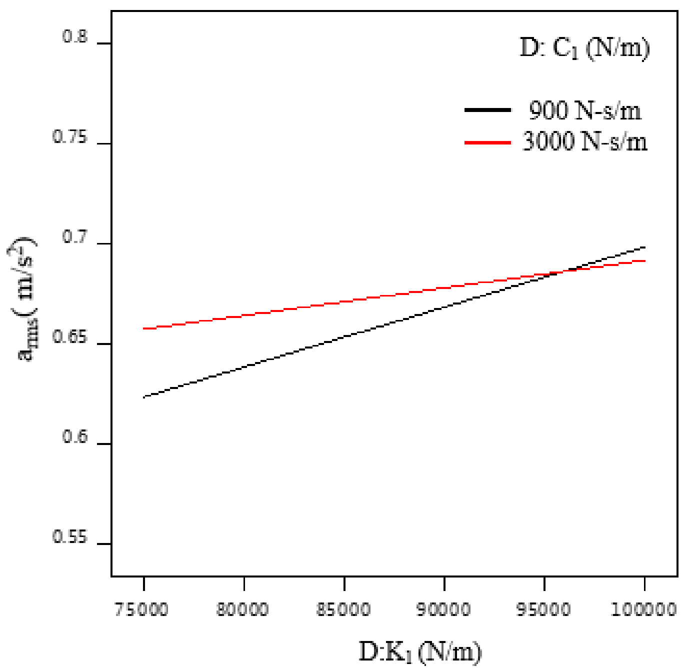

Figure 5: Interaction plot between car suspension spring (K_1)and car damper (C_1) at C_p 650 N-s/m and K_p105000 N/m

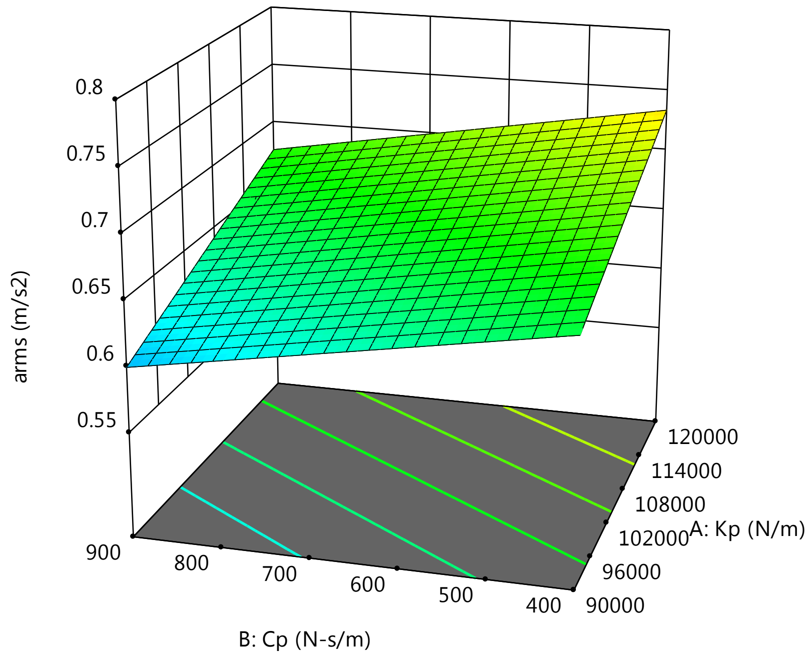

Figure 6: 3D surface graph for a_{rms}(ride comfort) at K_1 87500 N/m and C_1 1950 N-s/m.

The three-factor interaction of seat stiffness (Kp), seat damping(Cp), and car stiffness(K_1), for a_{rms} (ride comfort) at constant car damping of 1950 N-s/m is shown in Figure 7.From the plot it is observed that the significantly low value of root mean square acceleration(a_{rms}) is obtainedwhen the seat stiffness (Kp) is set to low level, seat damping (Cp) to high level, and car stiffness(K_1) at high value. This means that high value of comfort is obtained at this suspension setting.

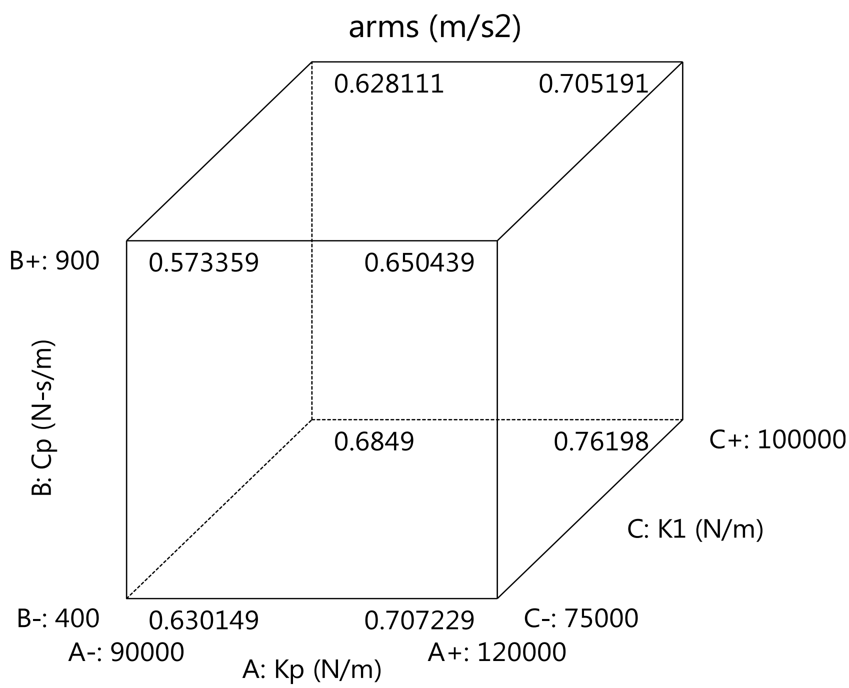

Figure 7: Three factor interaction cube plot for a_{rms} (ride comfort) at C_1value of 1950 N-s/m.

VI. CONCLUSION

The article aims to study the effect of suspension and seat parameters on ride comfort of occupant while travelling. A quarter car model along with the seat has been used in the present work. the weightage root mean acceleration at the seat occupant interface has been determined in accordance with the guidelines of ISO 2631 standards using bond graph methodology. The empirical relation between the car parameters and the weighted rms acceleration i.e. ride comfort has been obtained using face centred central composite design (CCD) of response surface methodology. The ride comfort prediction model in terms of root mean square acceleration is developed using regression analysis and it has showed a good agreement with the simulation results. All the selected parameters have been identified as significant and have significant effect on ride comfort. Also, good comfort has been obtained when the seat stiffness (Kp) has been set to low level, seat damping (Cp) to high level, and car stiffness(K_1) at high value.

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