

Enhancement of Driver Ride-Comfort through Reduction of Transmitted Vibrations by using Different Materials for Car Seat Cushion



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Abstract: *The aim of this work is to simulate reduction of whole-body vibration represented by acceleration that is transmitted through seat to the driver in a passenger car by studying different cushion materials for the seat. The accelerations at the interface of driver and seat are studied for an exposure period of eight hours as per ISO 2631-1(1997) standards. The entire study is done using FEA analysis in ANSYS 19.2. The simulation has been carried out for three different base accelerations representing three different road conditions and also for three different weights of drivers which are assigned to the manikin model sitting on the seat. Two cushion materials namely melamine foam and rebonded foam, in addition to regufoam which is commonly used in the cars have been taken up for study. For 65 kgf, 75 kgf and 85 kgf driver weights, rebonded foam results in an average A(8) reduction by 13.8%, 19.48% and 30.34% respectively whereas melamine foam has reduced it by 5.19%, 5.80% and 14.54% respectively for the same conditions. It is therefore suggested that rebonded foam gives better comfort compared to the existing regufoam and melamine for seat cushioning of the car studied.*

Keywords : *car seat, cushion material, foam, simulation, whole-body vibration.*

I. INTRODUCTION:

Over the past few decades, cars have become the preferred means of transport all over the world since they offer, among other advantages, independence, comfort, pollution-free ambience and relative safety for the occupants. Riding comfort, especially of the driver, is hence receiving increasing attention from automobile manufacturers and researchers. Next to road quality-on which the car manufacturer has no control-seat design directly influences ride comfort. In general the car seat is a structural steel frame over which a polyurethane foam cushion is placed. Base vibrations are created by the road profile, especially at high car speeds, and are transmitted to the chassis of the car. These vibrations are modified by the seat frame and are partly absorbed by the cushion material on top of the seat.

Unfortunately however, the remaining unabsorbed vibration is transmitted to the driver causing discomfort. Mondal and Arunachalam [1] state that both cushion and the body of the driver exhibit nonlinear mechanical response on vibration.

Vehicle defects like misalignments of moving parts, wear and tear of components, inefficient suspension systems contribute to vibration and cause discomfort to the occupants and especially to the driver.

Burdzik and Konieczny [2] opine that analysis of complex vibrations occurring in vehicles should be conducted since the effect on the driver's and passengers' exposure to whole-body vibration (WBV) can range from short-term body discomfort and inefficient performance to long-term physiological damage. Estimation of WBV in cars has become essential as drivers exposed to WBV can be at increased risk for musculoskeletal disorders including low back problems, neck problems, and muscle fatigue. Long-term exposure to WBV puts workers at an increased risk for low back and spine disorders as pointed out by Kasara et al. [3]. Exposure to WBV should be monitored to ensure that daily exposure is below the upper boundary as specified in ISO 2631-1(1997). This standard for WBV, listed by Killen and Ege [4] is the assessment of vibration done by calculating the frequency weighted accelerations in three directions viz., along the X-, Y-, Z- axes. Discomfort is essentially subjective in nature since different individuals could perceive the same vibrations as different levels of discomfort. However, it is common practice by researchers to consider cushion-thigh interface acceleration as a quantitative measure of driver discomfort. Mehta and Tiwari [5] defined an ergonomically designed car seat as one that gives good support to the driver under dynamic conditions, reduces the transmission of vibration from the car to the body of the operator and in general, provides a comfortable ride. The commonly preferred material for automotive seat cushion manufacturing is open cell polyurethane (PU) since it provides a significant decrease in weight-to-performance ratio when compared to more traditional steel spring seat support system. Gouw et al. [6] developed a seat suspension model with two-degrees-of-freedom to help designers in the selection of optimal suspension parameters for off-road vehicles. They studied the correlation between analytical and experimental acceleration transmissibility by coupling human to the seat through a linear spring and damper representing the seat cushion. They concluded that the most important factors affecting acceleration transmissibility are seat suspension spring stiffness and damping, as well as cushion properties. Berger and Gilmore [7]

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through their research developed an optimal method for selecting the seat dynamic parameters on a seat model with two-degrees-of-freedom and defined four design variables viz., seat suspension stiffness and suspension damping, seat cushion stiffness and cushion damping to be the parameters affecting ride comfort in car drivers. Vertiz and Gurram [8] made a study that facilitates proper selection of cushioning material suitable to meet the requirements of the users. They also describe various methods for evaluating cushioning materials for static and dynamic comfort. Seat design has been conducted in the past without the benefit of a clear understanding of the dynamic characteristics of the cushion materials used. Seat cushioning materials provide damping effects to reduce vibration transmitted to seated operator. It is therefore required to quantify the amount of damping present in the material. Such a quantification of damping is extremely useful for benchmarking and developing mathematical models of the dynamic behavior of cushioning materials. This paper describes how, through computer aided simulation, the damping characterization of different seat cushion materials are evaluated to estimate the A(8) value. In other words, the present paper outlines the work that has been carried out by the authors in assessing the vibration levels by numerical simulation and mathematical modeling.

II. PROCEDURE FOR PAPER SUBMISSION

Materials and Methods:

Two additional foam materials viz. melamine and rebonded foam are chosen for experimentation. The accelerations obtained between the seat cushion and human body interface are compared with those obtained for the existing car seat cushion which is usually made up of polyurethane regufoam. Rebonded foam is a molded polyurethane product made from pieces of shredded flexible polyurethane foam, held together with a binder. It has higher density and excellent resilience and is thus suitable for applications including vibration sound dampening and cushioning. Melamine is a high resilience lower density material, lesser than that of regufoam and rebonded foam. All the materials are of uniform thickness of 120 mm. Apart from these materials the seat frame is considered to be made of structural steel, and the human manikin is given the soft tissue properties. The mechanical properties of all the materials used are shown in Table 1.

Table 1. Mechanical properties of materials used

S.No	Material	Density (kg/m ³)	Young's modulus (kPa)	Poisson's ratio
1	Polyurethane regufoam	41	20	0
2	Melamine foam	8.35	16	0.44
3	Rebonded foam	64	13	0.3
4	Structural steel	7800	2.10E+08	0.3
5	Soft tissue for manikin	1100	150	0.46

EXPERIMENTAL WORK:

1. Modelling:

The driving seat of a Maruthi Celerio is chosen and modeled in CATIA V5 R20. A manikin, also modeled in CATIA V5R20, is made to sit on the seat in a fixed driving posture of at an angle of 110° with the seat top. The legs of the

driver stretch forward at an angle of 45°. The car seat model, manikin and the assembly are shown in Fig 1.a-d.

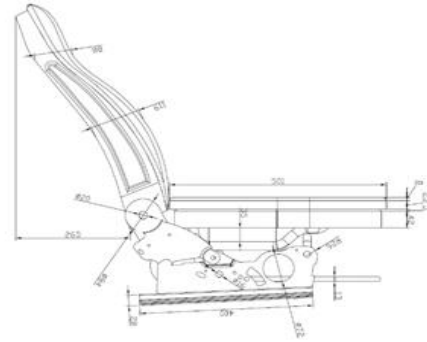


Fig 1. (a) Seat frame with dimensions

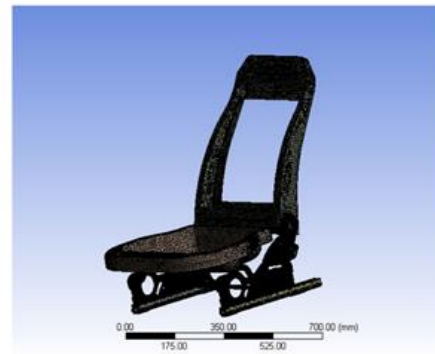


Fig1(b) Model of the Seat frame



Fig. 1(c) Model of a human manikin

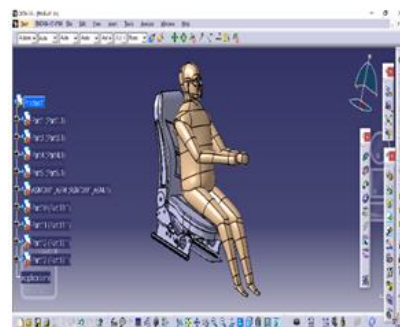


Fig. 1(d) Seat and manikin assembly

a_w = Weighted RMS acceleration in m/s^2
 T_i = Time of exposure in hours.

III. ANALYSIS

Meshing: Modal analysis of a human subject model in sitting posture assembled with seat has been performed using FEM in ANSYS 19.1 workbench. A fine mesh is generated with tetrahedral elements as they can fit complex geometry better. Amid investigation, limit conditions were taken by considering both feet and seat base to be fixed and physical properties of a human subject have been assumed as homogeneous and isotropic in nature. Grid convergence is tested by reducing the element size from default mesh size of 65 mm having 133,584 nodes and 50,492 elements to 5mm mesh size containing 336,532 nodes and 150,339 elements since it was found that on further decreasing the mesh size there is no discernible change observed in the frequencies. The grid convergence plot for the four global modes such as Seat backrest tangential mode, seat bending mode, backrest bending mode and torsional mode numbered from mode 1 to mode 4 respectively is shown in Fig. 2 below.

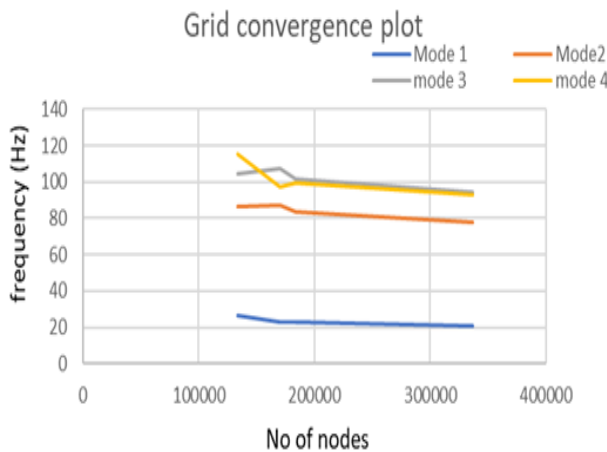


Fig 2. Grid convergence plot for no of nodes verses frequency.

Harmonic analysis is done in ANSYS 19.2 for estimating the acceleration between the seat and human interface. The assembly of the human manikin and the seat is excited at the fixed base with an acceleration of $1m/s^2$, $2m/s^2$, and $3m/s^2$ representing smooth, medium and coarse roads respectively. The excitation is given separately for x, y and z axis directions where z is considered along vertical, y is considered as the direction of motion of the vehicle and x along the horizontal lateral direction, for 65kg, 75 kg, and 85 kg weight of the driver manikin. In all the cases the acceleration between the driver and the seat cushion is measured for estimating the ride comfort. The study has been carried out first with regufoam polyurethane and the same is repeated by changing the cushion material with melamine and rebounded foams for all the three directions, road and weight conditions separately. The accelerations thus acquired are tabulated in Tables 2,3 and 4 and plotted in Fig 3,4,5 which are further used to calculate the $A(8)$ value which defines the daily recommended transmissibility and is highly influenced by the frequency-weighted acceleration. The $A(8)$ value is calculated by the equation.

$$A(8) = \sqrt{\frac{1}{8} \sum_{i=1}^n a_w^2 T_i}$$

where,

IV. RESULT AND DISCUSSION

Weight (kgf)	Direction of acceleration	REGUF OAM	MELAMINE foam	REBONDED foam
65	Acceleration in X-Direction (m/s^2)	0.272	0.122	0.079
	Acceleration in Y-Direction (m/s^2)	0.168	0.146	0.09
	Acceleration in Z-Direction (m/s^2)	0.493	0.442	0.381
75	Acceleration in X-Direction (m/s^2)	0.233	0.106	0.077
	Acceleration in Y-Direction (m/s^2)	0.163	0.111	0.071
	Acceleration in Z-Direction (m/s^2)	0.457	0.426	0.367
85	Acceleration in X-Direction (m/s^2)	0.221	0.058	0.058
	Acceleration in Y-Direction (m/s^2)	0.148	0.107	0.053
	Acceleration in Z-Direction (m/s^2)	0.419	0.381	0.316

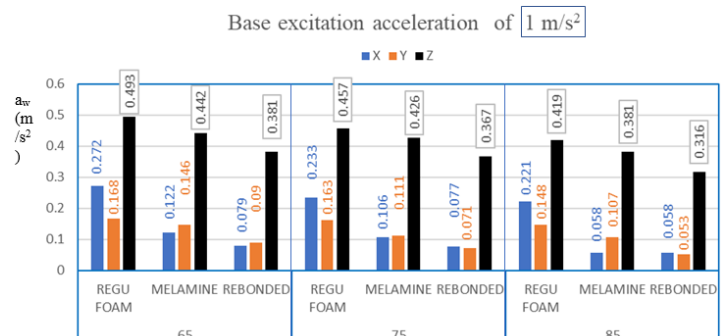


Fig. 3. Acceleration for different materials and weights at 1m/s base acceleration

Table 3. Acceleration values $A(8)$ with input of $2 m/s^2$

Weight (kgf)	Direction of acceleration	REGU FOAM	MELAMINE foam	REBONDED foam
65	Acceleration in X-Direction (m/s^2)	0.29	0.141	0.136
	Acceleration in Y-Direction (m/s^2)	0.185	0.174	0.146
	Acceleration in Z-Direction (m/s^2)	0.884	0.876	0.844
75	Acceleration in X-Direction (m/s^2)	0.213	0.135	0.134
	Acceleration in Y-Direction (m/s^2)	0.174	0.166	0.111
	Acceleration in Z-Direction (m/s^2)	0.852	0.844	0.806
85	Acceleration in X-Direction (m/s^2)	0.133	0.127	0.058
	Acceleration in Y-Direction (m/s^2)	0.17	0.148	0.101
	Acceleration in Z-Direction (m/s^2)	0.84	0.837	0.367

Enhancement of Driver Ride-Comfort through Reduction of Transmitted Vibrations by using Different Materials for Car Seat Cushion

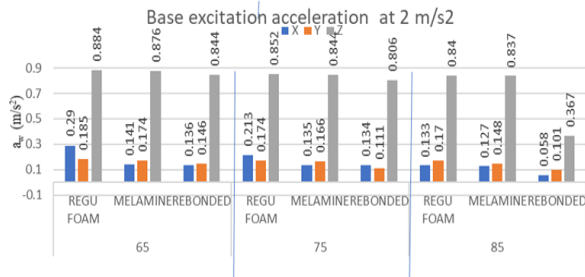


Fig. 4. Acceleration for different materials and weights at 2 m/s² base acceleration

Table 4. Acceleration values A(8) with input of 3 m/s²

Weight (kgf)	Direction of acceleration	REGUFOAM	MELAMINE foam	REBONDED foam
65	Acceleration in X-Direction (m/s ²)	0.381	0.337	0.32
	Acceleration in Y-Direction (m/s ²)	0.333	0.322	0.301
	Acceleration in Z-Direction (m/s ²)	1.175	1.155	1.151
75	Acceleration in X-Direction (m/s ²)	0.328	0.323	0.316
	Acceleration in Y-Direction (m/s ²)	0.316	0.312	0.296
	Acceleration in Z-Direction (m/s ²)	1.297	1.24	0.995
85	Acceleration in X-Direction (m/s ²)	0.317	0.313	0.311
	Acceleration in Y-Direction (m/s ²)	0.315	0.303	0.291
	Acceleration in Z-Direction (m/s ²)	1.155	0.997	0.945

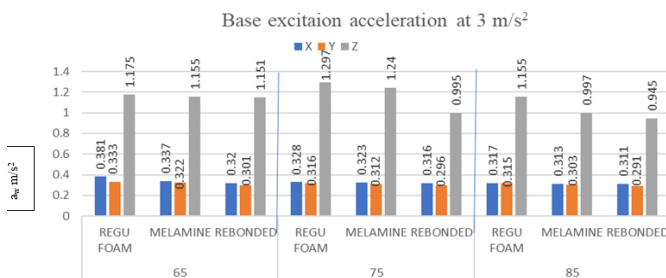


Fig. 5. RMS acceleration for different materials and weights at 3 m/s² base acceleration

Weight kgf	Base excitation Acceleration m/s ²	Polyurethane Regufoam A(8) m/s ²	Melamine foam A(8) m/s ²	Rebonded foam A(8) m/s ²	Percentage reduction	
					Melamine %	Rebonded %
65	1	0.17	0.16	0.13	6.25	30.76
	2	0.31	0.29	0.3	6.89	3.33
	3	0.44	0.41	0.41	6.81	7.31
75	1	0.16	0.15	0.13	6.66	23.07
	2	0.3	0.29	0.26	3.44	15.38
	3	0.42	0.41	0.35	2.43	20
85	1	0.15	0.13	0.11	15.38	36.36
	2	0.3	0.27	0.23	11.11	30.43
	3	0.41	0.35	0.33	17.14	24.24

In the present experimental simulation three essential parameters namely base excitation (to represent road condition), weight of the driver and the seat cushion material have been tested. As the base excitation is increased the A(8) value which is calculated for one hour exposure time is increased four times its value at 1 m/sec² for all the weights of the driver and cushion materials the values of A(8) have been tabulated in Table 5. It is observed that the A(8) value is not effected for weights 65 and 75 kgf in the case of melamine foam but a decrease of 15% was

observed for the weight 85kgf. The reason for the better performance of rebonded foam could be that since it has more resilience and better compressive strength than the regufoam and melamine foam. So the change in weight has shown markable effect in decreasing the A(8) value to a maximum of 20 % for the given three weights and accelerations as shown in Table 1. In addition, Table 2 shows the comparison of average reduction in A(8) values by replacing regufoam with melamine foam or rebonded foam. The melamine foam has reduced the A(8) value by 14.54 % at a weight of 85 kgf of the driver and rebonded foam has decreased it by 30.34 % for the same weight, as shown in Table 6.

Table 6. Average percentage reduction of A(8) values obtained for different base excitations for the materials compared to regufoam

Weight (kgf)	Melamine Foam (%)	Rebonded Foam (%)
65	6.65	13.8
75	4.17	19.48
85	14.54	30.34

V. CONCLUSION

Rebonded foam material shows considerable decrease in A(8) value compared to existing foam of the car seat and even melamine foam. Value of A(8) has reduced by about 12 to 30% on all road and driver weight conditions whereas melamine shows a reduction of 5 to 14 % in A(8) values. It can be concluded that melamine foam also has reduced A(8) values but not to the extent of rebonded foam. Hence it is recommended that the existing polyurethane regufoam needs to be replaced by rebonded foam for better ride comfort for drivers in passenger cars.

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