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Lightweight Options for Seat Structure in a Bus

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ABSTRACT

As seat is the most priority component in vehicles while considering the comfort. Factors like ergonomics, safety and smooth ride can be achieved by designing an effective seat structure. Light weighting of vehicles are dominant in present era due to the tremendous CO_2 emissions in environment. By specifying various domains like flooring, roof structure, seats etc. light-weight can be achieved. As earlier mentioned, seat gives us high weight reduction potential for light weighting purpose. The modeling is done by considering the ergonomics, safety, weight and cost related issues. Further, study elaborates the analysis regarding static, vibrational and durability responses. Different strength parameters like bending stiffness, tensile stiffness and torsional stiffness are considered. By using composite material, 41.5 % weight reduction is achieved with 33.6 % considerable cost increase.

Keywords - AIS-023, GFRP, Seat Structure, Analysis, vibration, stiffness, Deformation, Cost Estimation, passenger, FOS, Magnification Factor.

1. INTRODUCTION

Buses are always one of the main and favorite sources of public transport. Bus seat can also cause severe injury to the occupants in case of frontal impact. Thus the seat structure of the bus should absorb sufficient energy to minimize the passenger injury [1]. Complex design parameters for seat design has always been challenging for engineers. The three main design objectives, to be satisfied simultaneously are comfort, safety and performance. For comfort, various ergonomic and human factors considerations are ranging from seat dimensions and adjustments to cushioning. Presently, large passenger vehicles are known to have a high risk of an injury due to accident and insufficient safety regulation. The strength of seat is one of the important issues that affect to injury level of passenger [2]. The development of seat structure has to fulfill different requirements [3].

Seat safety is expected and assumed by the customer. Therefore, suitable structural strength and design of the seat are very important to prevent injuries and passenger life [4]. Overall 20% weight reduction was achieved by developing lightweight seat prototypes. Current lightweight share is highest in aviation with almost 80 percent; also automotive sector is massively increasing its share from 30 to 70 percent by 2030. Much weight reduction has been achieved by material substitution and innovative design techniques in several parts. Lightweight materials and design have always been an important topic in product design across several industries [5]. There are different applications to diminish the heaviness of mass travel vehicles, for example, supplanting the body structure or individual segments with lightweight materials. Among the advances, reducing auxiliary weight is a standout amongst the most critical methods for diminishing fuel utilization and enhancing the execution of vehicles. Approximately 75% of the average motor vehicle's fuel consumption is directly related to factors associated with vehicle weight. Also, the seat structures are particularly important for lightweight design since each seat weigh on an average of 12.5 kg [3].

2. LITERATURE SURVEY

Recently, there have been growing concerns over fuel consumption and pollution caused by the increasing number of automobiles, and the automotive industry is under great pressure to reduce fuel consumption and emissions. The shortages of energy sources and global warming have put increasing pressure on the investigation of new materials and the development of new products and technologies for the automotive industry [6]. Industrial equipment exposes individuals to whole-body vibration (WBV) and mechanical shock. This exposure can adversely affect their health, safety, comfort, as well as, working efficiency and performance [7]. Lightweight materials and design have always been an important topic in product design across several industries. The concept has been most important in aviation but also in industries. While the relevance of lightweight materials cuts across industries [8]. Tata Steel studied the front seat and developed a basic front seat frame which allowed side impact load to be transmitted to improve side impact occupant protection but no design or thickness optimization was undertaken [9]. Long fiber thermoplastics (LFTs) are increasingly being used in automotive applications for front-ends, bumper beams, dashboards, and under body shields. They have a significant potential for mass-transit applications in buses, trucks, and railroad vehicles. Bus seat was chosen as a candidate component to assess the viability of LFT technology to reduce weight and cost, without compromising performance [10]. The function of automotive seating is to support, protect and to provide comfortable seating posture to its occupants [11]. Design concept uses comfort cutout areas, which allow optimization of seating comfort [12]. Automotive passenger seating comfort is strongly influenced by the WBV. The dynamics of the coupled seat-body system is a complex phenomenon. The static and dynamic properties of PUF cushion and its support may depend upon different variables [13]. Automotive industry relentlessly is in a quest for higher performance of vehicles in aspects mainly for increased fuel efficiency. Since 1920's, steel has been main material in automotive industry [14]. Seat structure of the bus should absorb sufficient energy to minimize the passenger injury [15]. In India, AIS023 (Automotive Industry Standards) is one of the several mandatory standards from CMVR (Central Motor Vehicles Rules) to ensure the seat strength and occupant safety during accidents. The purpose of the seat development cycle for designing a seat that may well fit in the diversity is of automotive environments [16].

3. MATERIAL STUDY

Table 1 Material comparison

S.No.	MTL	Density (g/cc)	Cost ($/kg)	UTS (MPa)	YS (MPa)
1	CFRP	1.5	110	550	200
2	GFRP	1.8	3.9	530	125
3	Mg	1.7	2.07	260	130
4	Al	2.7	1.8	570	500
5	MS	7.8	0.5	380	200
6	AHSS	7.8	0.25	1550	1240
7	SS	7.8	2.75	590	240

It can conclude from the above Table 1, that though the values of AHSS looks higher than other material but it is available in only stamped shapes. So, GFRP and Al-alloys are the best suitable materials than the conventional Yst 240 steel grade and other materials listed in the above Table I.

4. METHODOLOGY

4.1 Modelling

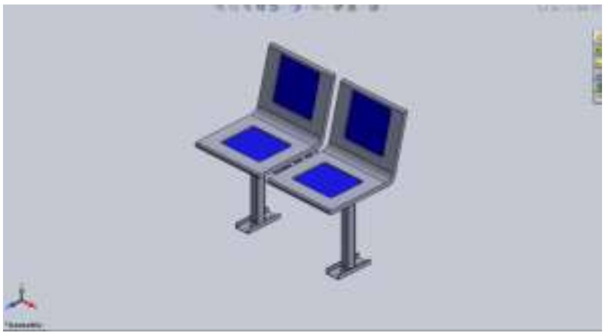

Fig.1 Assembly of 2x2 seat layout

The seat model including both its frame and upper seat is done in Solidworks software. In this, each and every part or subassembly is drawn and then moved towards the assembly section. Assembly of 2x2seat layout is shown in Fig.1. Also, the accessories like closing caps and bolting nuts are kept as per the standards prescribed. For tubular or hollow sections they generally require closing caps. Bolting nuts of M8 grade are used. All the parts are modeled in SolidWorks software. The main parts in the seat model are as follows:-

- BRT (Back Rest Tube)
- BSM (Bottom Support Member)
- Channel Section (Bolting)
- Seat support tube

4.2 Meshing

Table 2 Mesh Statistics

SR.NO.	Parameters	Values
1	Element Size	1mm
2	No. of nodes	1141484
3	No. of elements	604404
4	Meshing Type	Mixed (Tri + Quad)

Meshing is done in ANSYS-14.5 package for single seater only. Further for 2nd phase i.e. for 2x2 layout is done in ANSYS packages. For meshing mixed (tri+quad) elements are used of size 1mm. The statistics related to nodes and elements are mentioned as above Table 2. Meshing is diversed in the regions where holes occur. Thus, stress concentration is seen out at the juncture of stiffener and BSM fitted.

4.3 Static Structural Analysis

Analysis is done for both static structural and modal types. In it, all the setup is initially generated and then it is further updated for solving purposes. Initially for 1st phase, the material is structural steel by default. All the properties related to structural steel are given in input conditions. Also, VM and maximum shear stress is found out. Also, respective strains are found out. FOS is calculated at the end of the analysis part. The following Table 3, shows the comparison of analysis results. It also shows that GFRP material shows the nearly same stress values as Yst 240 so, it is recommended to go for GFRP.

Table 3 Comparison of various parameters with different materials

S.No.	Parameters	Mtl (Yst 240)	Mtl (AA6061)	Mtl (GFRP)
1	TD (mm)	0.115	0.436	0.582
2	VM Stress (MPa)	29.71	30.22	28.51
3	VM Strain	$1.49E^{-4}$	$4.39E^{-4}$	$10.96E^{-4}$
4	FOS	8.08	9.13	4.53

4.4 Modal Analysis

Table 4 Mode frequencies for LDPE material

S.No.	Mode	Freq. (Hz)
1	1st	371.43
2	2nd	402.74
3	3rd	437.54
4	4th	514.09
5	5th	602.01
6	6th	665.78

Table 4 shows, the modal frequencies of upper seat for LDPE material. In this, the frequency increase gradually with least value of 371.43 Hz to max. of 665.78 Hz. It is also shown in the following Fig. 2.1 and 2.2 respectively.

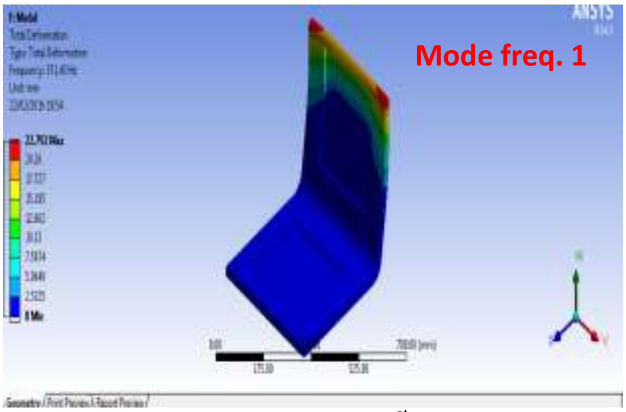

Fig. 2.1 Frequency at 1st mode

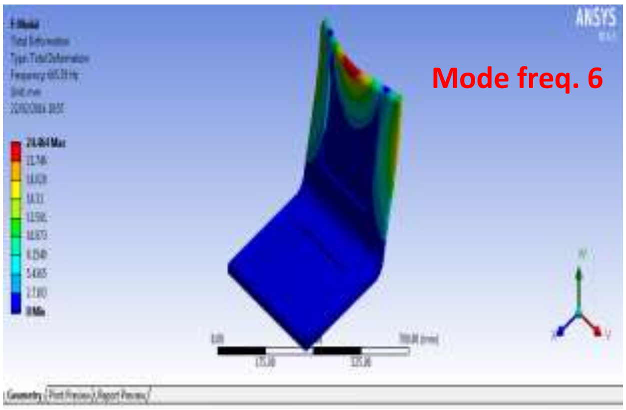

Fig. 2.2 Frequency at last mode

5. COST ESTIMATION

Table 5 Final Cost Estimation

S.No.	Particulars	Qty.	Cost (INR)	Wt. (kg)
1	Upper Seat (upholstery and fabric)	2	700	6
2	Seat Components	13	1423	7.443
3	Fasteners	106	850	1.180
4	Welding Cost	NA	500	NA
Total			3473	14.7

Cost Estimation is made considering various factors like raw material, manufacturing and end product. These factors are considered to draft approximate cost estimation. Further, in it welding cost is needed to be added. Other miscellaneous costs like transportation costs, service costs are to be taken into consideration. The observation suggests that by using GFRP as alternative considerable weight reduction takes place. But, also cost increase is more compared to conventional steel material. The percentage increase for cost shows the rise upto 46 % as compared from Steel to GFRP materials. The 46 % cost increase is regardless for the individual components only. Again applying for MOQ (minimum order quantity) may further reduce the percentage cost increase. Weight reduction is considerably achieved upto 77 % from switching the material to GFRP as that of Steel.

The cost estimation for initial seat was around 2600 INR for two seater layout. The above table V, shows the details of cost and weight for 2x2 seat layout. New estimation for cost shows the increase of 33.6 % in it. Also, weight is reduced upto 41.5 % which is 14.7 kg from the previous of 25 kg for two seater layout in bus.

6. CALCULATIONS

6.1 Magnification Factor (MF)

Table 6 MF at diff. excitation freq. for AA 6061

Part Name	Fn (Hz)	MF @ F=50 Hz	MF @ F=100 Hz	MF @ F=500 Hz	MF @ F=1000 Hz
BRT	1466	1.0011	1.0043	1.1184	1.6658
BSM	1163	1.0017	1.0068	1.2004	2.3172
Channel	841	1.0032	1.0131	1.4520	1.5850
Support Tube	1450	1.0011	1.0044	1.1213	1.6876

From above Table 6, it is shown that the MF at different frequencies for different seat components. The channel section shows nearly same MF values for lesser frequency as compared to other components.

6.2 Exact Frequency (Fn)

Table 7- Comparison of Exact and FEA solutions for GFRP (1st mode)

Part Name	Fn @ 1mm		Fn @ 2mm		Fn @ 3mm	
	Exact	FEA	Exact	FEA	Exact	FEA
BRT	1175	883	1530	1094	1948	1352
BSM	1091	874	1126	877	1195	876
Channel	643	446	896	624	1049	740
Support Tube	727	508	1524	1073	2353	1715

The above Table 7 shows the comparison of exact frequencies and FEA frequencies calculated at various thicknesses respectively.

6.3 Percentage Error

Table 8 Error (%) values for diff. thks of Yst 240

S.No.	Part Name	(%) Error @ t=1mm	(%) Error @ t=2mm	(%) Error @ t=3mm
1	BRT	22.58	14.95	15.37
2	BSM	27.61	25.53	27.58
3	Channel	31.85	32.69	31.28
4	Support Tube	21.72	21.51	20.45

Percentage error is calculated for different seat components considering Yst 240 material across different thickness as shown in above table VIII.

7. RESULTS AND DISCUSSIONS

It is observed from the Fig. 3, that there is no increment in value of MF for BSM component and channel section shows substantial increase in the values of MF. BRT and support tube shows similar variations in MF. Both highest and lowest MF values are recorded for seat support tube component.

It is observed from the Fig. 4, that the percentage error records lowest value (14.95%) for BRT (t=2mm) whereas highest value (32.69%) for channel section (t=2mm) respectively. Also, the variation for error percentage is more or less the same for different components considering Yst 240 as material.

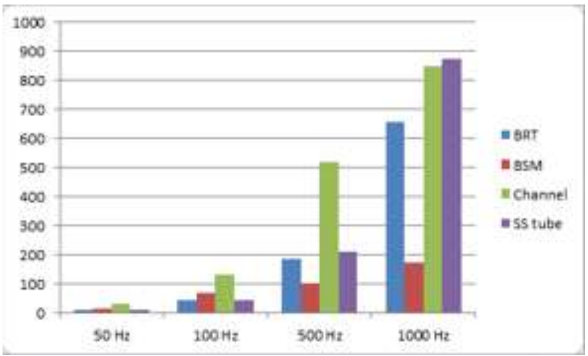

Fig. 3 Graph shows the variation of MF @ diff. excitation frequencies for AA 6061 material

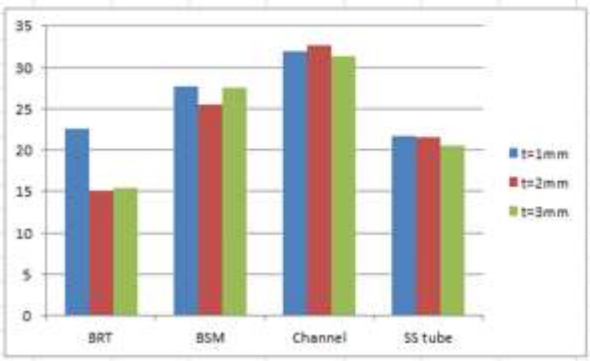

Fig. 4 Graph of Yst 240 Error (%)

Table 9 Modal frequencies at diff. thickness [Yst 240]

S.No.	Part Name	Fn (Hz) @ t=1mm	Fn (Hz) @ t=2mm	Fn (Hz) @ t=3mm
1	BRT	1464	1980	2401
2	BSM	1146	1167	1166
3	Channel	599	836	1028
4	Support Tube	681	1460	2299

Modal frequencies at different thicknesses indicate (as tabulated in Table 9) that there is tremendous frequency change for components like BRT, Channel and Support Tube whereas minor changes occur for the BSM component irrespective of the material used.

8. CONCLUSIONS

Modal frequencies at different thicknesses indicate that there is tremendous frequency change for components like BRT, Channel and Support Tube whereas minor changes occur for the BSM component irrespective of the material used. The percentage error records lowest (19.89%) for BSM (t=1mm) whereas highest (30.64%) for Channel Section (t=1mm) respectively. Compared to AA 6061 the variation is drastic change which indicates the increase for BRT and BSM components; whereas for other components the change is normal. This implies that the fiber distribution, its elastic nature and also the value of Yield Strength might rely for greater percentage error change of GFRP as compared to AA 6061 material.

The 46 % cost increase is regardless for the individual components only. Again applying for MOQ (minimum order quantity) may further reduce the percentage cost increase. Weight reduction is considerably achieved upto 77 % from switching the material to GFRP as that of Steel. Thereafter, total of 33.6 % cost is increased as to the 41.5 % weight decrease; compared to the previous results or statistics for 2*2 seat layout. Future scope suggests for developing new materials for upper seat and advancements such as 'Loft Seat' developed by Johnson Controls. Electric seating can be considered as of prime importance for HCV's which can be termed as the future of passenger bus seats.

9. FUTURE SCOPE

In any automobile, seats play a critical role both for the driver and passenger experience. Vehicle technology is constantly being improved, and it's far more than just the engines and safety features. Even seats come under scrutiny, and a new design under development could dramatically change the scenario. Modular design concepts have seen past from the many companies that accord towards both car and buses respectively. Also, advancements in seat mechanisms can be seen through the many automobile companies. Advancement called as 'Loft Seat' designed by Johnson Controls (leading manufacturer in automotive seating) embarks the idea of designing modular seat components.

This phenomenon can be shifted on priority basis for the HCV's. Also, the concept seat includes the high-level armrest for comfort and also the high quality upholstery which meets the standard requirements. Electric seating can be considered as of prime importance for HCV's which can be termed as the future of passenger bus seats.

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