Optimization of Bus Body Structure

Sangeeth N
Senior Manager
Ashok Leyland
Sangeeth.N@ashokleyland.com

Arindam Mukherjee
Manager
Ashok Leyland
Arindam.Mukherjee@ashokleyland.com

Keywords: Topology- Optimization, Size-Optimization, DOE.

Abstract
Design concepts evolve with addition of value to benchmark designs based on the experience and imagination of the designer.

This paper deals with the optimization study done for a new bus program at the concept level to achieve an optimum material layout and load-paths to arrive at feasible designs. Optimization based on FE models require simulations to be executed several times. For a large structure like bus, it is challenging because the total time for running the simulations will not fit into the program time lines. To overcome this, innovative FE model building was employed to reduce the individual analysis time.

Design optimization techniques such as topology optimization study helps to quickly generate new ideas at a concept level and to reduce the cycle time for the numerous design iterations. The result of the topology study was used in positioning the structural members. Once positions are finalized, the dimensions of structural members were optimized by performing size optimization. A range of tube sections were used as an input for the DOE and optimum sections at various locations were arrived. Torsional stiffness and modal frequency targets were used as constraints.

This study at the concept level has helped in giving a direction towards attaining optimum weight for a bus body structure in a short time.

Introduction
Vehicle structures used in the industry depends upon the application and end user requirements. The vehicle structure must be evaluated for various loading patterns to simulate real time application. In conceptual design stage, it is critical to assess these various design configurations and arrive at the optimized design. A small reduction in overall weight will result in huge operational cost savings. Thus, it is imperative to use optimization tools to effectively decide the optimum dimensions for channels and tubes.

The optimization methods used in this paper are topology optimization and size optimization. In topology optimization, the flow of stress or load paths is identified. With these identified positions, size optimization is done to increase the overall stiffness of the vehicle with minimum material.
Topology Optimization
Process Methodology
For topology optimization the roof, sides, front and rear structure of the bus was considered as a flat plate. Torsion and bending load cases were considered. The objective function was maximization of structural stiffness with constraints on percentage of material removal.

![Initial design space and Topology optimization results](image)

Figure 1: Obtaining load path flow by Topology Optimization.

Results and Discussion

In roof structure, the optimized structure suggested a series of cruciform joints which will increase structural stiffness and improve torsional stability. Near the corners and the periphery of the roof additional material was suggested. Above the door opening the roof structure needs to be strengthened for allowing load transfer from LH to RH side of the vehicle.

![Roof structure load flow paths](image)

Figure 2: Roof structure load flow paths in Topology Optimization

At the front and rear a V shaped structure was recommended for better transfer of load from the LH side to the RH side.

![Front structure load flow paths](image)

Figure 3: Front structure load flow paths in Topology Optimization
Wheel arch area at front and rear are critical for load distribution throughout the structure. Thus, a cross shaped reinforcement was advised. Having load bearing members forming a ring structure at the locations of side pillars is suggested for optimized designs. This will help transfer loads from one side of the structure to other side without causing local flexure.

Figure 4: Side structure load flow paths in Topology Optimization

Size Optimization
Process Methodology
The result of the topology study was used in positioning the structural members which were modeled with beams of respective cross sections. The beam model was selected for reduction in time for simulation, thus allowing more iterations within a given time frame. The beam structures were then categorized into five major groups: Window pillars, Window rails, Diagonal members, Cantrail and Roof cross members. DOE study was conducted with design cross sections as variables which are assigned to the identified groups. This effectively puts a constraint that the sections used within a group should be of same sectional properties. The objective of the DOE study was to find out the combination of variables which provides the required stiffness in torsion, bending and meets natural frequency requirements of the structure, with least mass.

Design Variables for Optimization

Figure 5: Variable selection for Size Optimization.
Results and Discussion
From the DOE study the optimal dimensions for design variables were obtained. It was observed that the Roof cross member, Window Pillar and Cantrail has major effect in Torsional Stiffness. In Bending load case, there was no significant changes on changing the cross section of the identified variable. A sample of the study is shown below.

![Response Table](image)

Figure 6: Response Table.

The effects of the variables are plotted and shown. For the variables the combinations, 0 refers Initial value, 1 refers Lower bound and 2 refers Upper bound.

![Main Effects Plot](image)

Figure 7: Main Effects Plot.
Optimized Structure
A suitable combination from the above results was recommended where Torsional stiffness is comparatively higher with minimum weight of structure.

![Figure 8: Suggested Combination.](image)

From the optimized values, the beam structure was converted to a 3D model. The 3D model was simulated under standard load cases of Torsional and Bending stiffness for static and obtaining natural frequency and mode shapes which are relevant for durability. A rollover simulation was also carried out and found satisfactory.

![Figure 9: 3D Realization. Figure 10: Torsional Stiffness Verification. Figure 11: Bending Stiffness Verification.](image)

Benefits Summary
Topology, size optimization eliminated number of simulations and reduced design cycle time. This study at the concept level has helped in giving a direction towards attaining optimum weight for a bus body structure in a short time. Approximately 500 hours reduced to 4 hours due to 1d beam modeling.

For vehicles in development stage, structural analysis is done first at the design evaluation phase. Based on the analyzed data, the design gets updated for increased strength, and iterations of design to evaluation continues till it stabilizes with the acceptable limits.

If at the concept stage of the vehicle if an optimization study is carried out, it could reduce the mass of the vehicle keeping its structural strength within defined limits, thus increasing the fuel efficiency of the vehicle. The data base created and the sensitivity information can be used to select sections based on the program weightage assigned for vehicle mass and stiffness.

Challenges
The locations identified by topology optimization should take into consideration the current assembly features in production. The cross hatched structure for roof is suitable under torsional stiffness, however it is difficult for an assembly process, thus iterations to be done to achieve a result which could be reproduced in the assembly line.

For variable chosen and bounds provided for DOE, it is essential that the manufacturing of those members is possible. It is a general practice to choose the limits of cross section and thickness from the range of tubes or channels that are currently under production.

Conclusions
This paper deals with the optimization study done for a new bus structure at the concept level to achieve an optimum material layout and load-paths to arrive at feasible designs. Design optimization techniques such as topology optimization study helps to quickly generate new ideas at a concept level and to reduce the cycle time for the numerous design iterations. The result of the topology study was used in positioning the structural members. Once positions are finalized, the dimensions of were optimized by performing size optimization. A range of tube sections were used as an input for the DOE and optimum sections at various locations were arrived. Torsional stiffness and modal frequency targets were used as constraints.

This study at the concept level has helped in giving a direction towards attaining optimum weight for a bus body structure in a short time.
ACKNOWLEDGEMENTS

For making this transformation sincere I would like to thank

Mr. Haridas P.T: HOD CAE – Ashok Leyland Product Development

Mr. Srinivas R: Bus Body Design Head – Ashok Leyland Product Development

Mr. Manikandan R: CAE – Ashok Leyland Product Development

Altair Support