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SIZE OPTIMIZATION TO IMPROVE THE DYNAMIC CHARACTERISTICS OF BODY IN WHITE STRUCTURE

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ABSTRACT

The dynamic behavior of a body-in-white (BIW) structure has substantial influence on the vibration and crashworthiness of a car. Initially, for most structures undergoing dynamic loading, it is essential to know the natural frequencies and the corresponding mode shapes. So, static torsion and bending tests are done to verify the stiffness of the body on which the durability of the entire car would depend. Modal analyses are done to find the natural frequency for the first torsion and bending modes under free-free boundary condition. Structure dynamic modifications are executed by using size optimization with the mass of the structure as the objective. Thus size optimization approach is proposed to improve the dynamic properties of Body In White (BIW).

Keywords: Bending Load, Torsional Load, Global stiffness, Modal Analysis, sizeoptimization

I. INTRODUCTION

Lightweight automobile has become the significant focus area of automobile technologies in 21st century. While the Indian automotive market is expanding in a rapid way, the major challenge faced by OEMs today is to provide light weight car body structure, with better fuel efficiency without conceding on the Ride and Handling performance. While designing the BIW we need to consider multiple disciplines, e.g. structural strength and stiffness, NVH and safety performance.

BIW optimization is a mathematical approach that optimizes material layout within a maximum or minimum value of a function of several variables subject to a set of constraints, as linear programming or systems analysis. This enhances the design performance while reducing the overall cost and weight factors. In this paper we have used structural Optimization tool “OptiStruct” in order to optimize the existing Design of a Low Weight Compact Car Body Structure and details of optimized design resulting in significant weight as well as cost reduction. One of the key challenges has been to maintain the body stiffness and torsional rigidity while reducing the weight.

In this paper, modal analysis was done to calculate the natural frequency and the corresponding mode shape of a BIW design. Free-free boundary condition is used to be consistent between results and the high repeatability. This approach is used in determining the global body stiffness of a structure with modal analysis tests. It is then compared to the operating frequency of the structure depending on the vibration that may be induced by a number of factors such as engine vibrations, road conditions, and suspension system

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II. 2-D MESHING

Once geometry clean-upof BIW [2] is completed (e.g. surfaces are stitched together no unwanted free surface edges inside the geometry), meshing is next.Quite often the geometry of thin walled 3D structures,is simplified to a geometric model with lower dimensionality. This is typically called a mid-surface model. The midsurface model is then meshed with 2-D elements. Thus, there is no need for a detailed volume mesh as the thickness of the geometry is virtually assigned to the2Delements.Mathematically, the element thickness (specified by the user) is assigned with half in the + Z direction (element top) and the other half in the – Z direction (element bottom).

Different quality parameters like skew, aspect ratio, included angles,jacobian, stretch, etc. are the measures of how far a given element deviates from the ideal shape. A square means that all of the angles are 90^0 with equal sides, while an equilateral triangle has all angles at 60^0 with equal sides. Some of the quality checks are based on angles (like skew and included angles), while others on side ratios and area (like aspect and stretch).

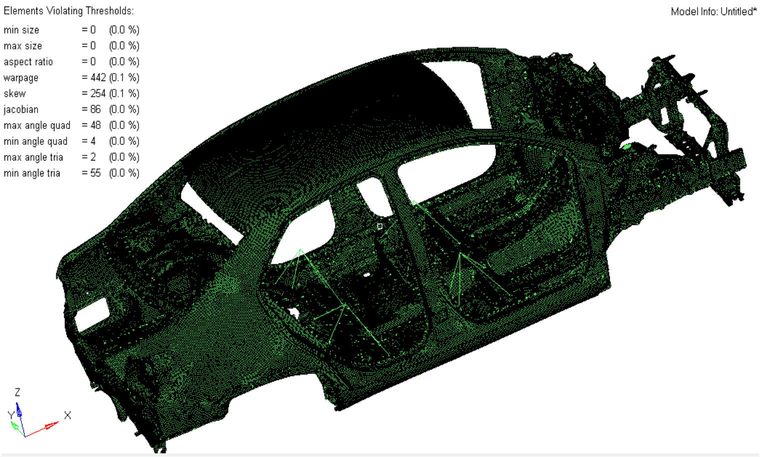

Figure 2.1 BIW – Quality Check

III. MODAL ANALYSIS

For the modal analysis, natural frequency was found by real eigenvalue analysis, which was done using Altair-Hyperworks and the corresponding mode shapes ignoring the damping. The results can be used to predict the dynamic behavior of the structure.In BIW,Static torsion and bending tests were done to verify the stiffness of the body on which the durability of the entire car would depend. For Torsional test the BIW structure was constrained at the suspension of rear wheel and couple loads of 1000N were given at the suspension of front wheel by creating RBE3 node. In Bending test the BIW structure was constrained at the suspension of rear wheel and front wheel by creating RBE3 node and loads of 1000N were given in the place of each passenger. Totally it contributes 4000N (4 passengers). The simulated values for static bending and torsion were 15.38 KN / mm and 7.979 KNm / deg.

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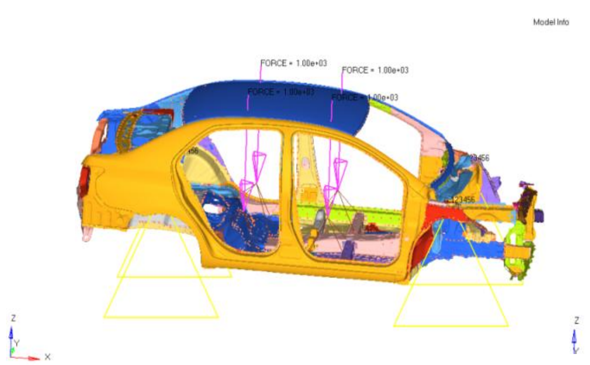

Figure3.1 BIW - Bending Test

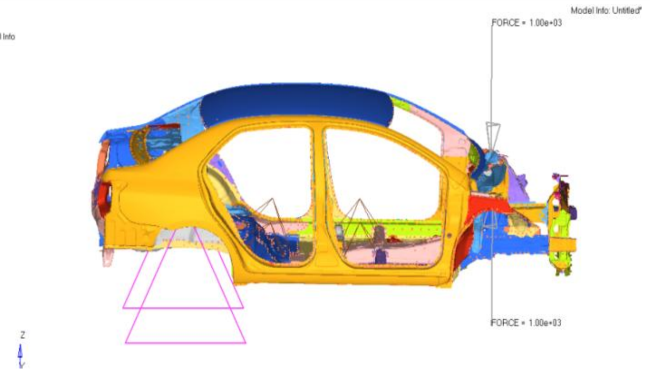

Figure 3.2 BIW - Torsional Test

Table 3.1 Bending Stiffness Calculation

BENDING STIFFNESS CALCULATION						
Z Displacement Rocker Center LH	Z displacement Rocker Center RH	Avg Z Displacement (mm)	Total Force (N)	No. of occupants	Total Load	Bending Stiffness – kN/mm
2.66E-01	2.66E-01	2.66E-01	4.00E+03	4.00E+00	4.00E+03	1.50E+01

Table 3.2 Torsional Stiffness Calculation

TORSIONAL STIFFNESS									
Z Displacement Front Shock L.H (mm)	Z Displacement Front Shock R.H (mm)	Avg Z Displacement (mm)	Force Applied (N)	Moment Arm (mm)	Twist (rad)	Twist (deg)	Torque (Nmm)	Torque (kNm)	Torsional Stifness – kNm/deg
1.40E+00	1.38E+00	1.388	1000	1126.57	0.0025	0.141	112657	1.1265	7.9795894

Modal analysis was then done to find the natural frequency for the first torsion and bending modes under free free boundary condition. The mass can also be calculated from the model to be used for the optimization analysis. A number of natural frequency values were taken from the modal analysis, where the modes were selected based on the shape formed by the displacement of the elements and these mode shapes are viewed using Hyperview.

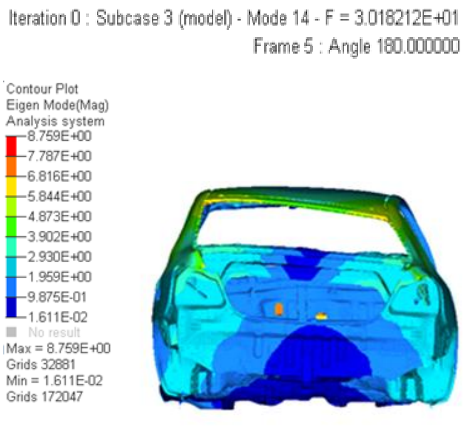

Figure3.3 Contour Plot of Torsional Mode

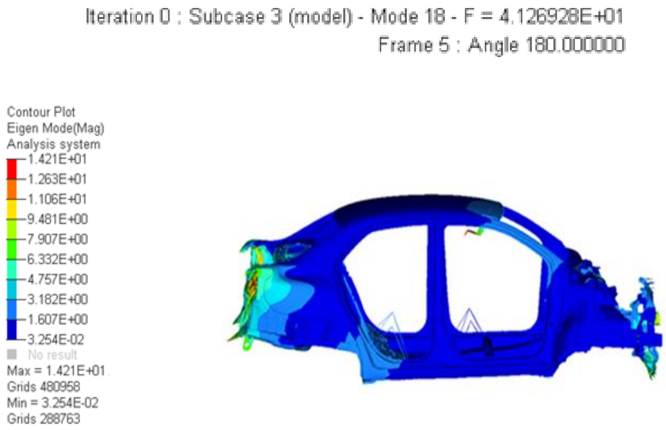

Figure 3.4 Contour Plot of Bending Mode

IV. STRUCTURAL OPTIMIZATION

Many engineering problems involve structural optimization [9]. Their goal is to satisfy certain requirements (e.g. limit state conditions) while minimizing certain quantities (e.g. resources spent) and maximizing others (e.g. structural safety). The requirements to satisfy are called restrictions and the functions to minimize/maximize are called objective functions.

Mathematically, structural optimization can be formulated by identifying the design variables, objective function, and constraints of the study. Basically, the general optimization problem can be expressed with the following for a single objective function.

Minimize $f\ (x)$

such that $g_j(x) \geq 0,\ j = 1, \ldots, n_g,$ (1)

$h_k(x) = 0,\ k = 1, \ldots, n_e,$

where$x$denotes a vector of the design variables. $h(x)$ denotes the equality constraint which is used when a constraintis set at a specific value. (x) is the inequalityconstraint and is used when the constraint needs to be withina certain limit. The inequality constraints are introduced inthis study, where the natural frequency of certain modesneeds to be increased to a specified value.

Size optimization defines ideal component parameters, such as material values, cross-section dimensions and thicknesses. It is used to determine the ideal thickness of a material based on the performance goals and the forces expected to be placed on the component during its life. In an optimization process, it is generally used after free-form optimization once the initial geometry of the component has been defined and interpreted.The behavior of structural elements such as shells, beams, rods, springs, and concentrated masses is defined by input parameters, such as shell thickness, cross-sectional properties, and stiffness. These input parameters can be modified in a size optimization process. The property of the material is not the design variable itself but is defined as a function of the design variable. It is defined by a design-variable-to-property relationship which is a linear combination of design variables such that

$$p = C_0 + \Sigma \mathrm{DV}_i \cdot C_i, \qquad (2)$$

wherep is the property to be optimized and C_i are linear factors of the design variable, DV_i. However, for simple gauge optimization of shell structures, the relationship changes where gage thickness will be identical to the design variable.

4.1 Size Optimization formulation

Size Variable: There are 230 Size variable

Constraint:

a) Displacement:

Torsion – Nodal Displacement< 1.3 mm

Bending – Nodal displacement < 0.25 mm

b) Natural Frequency :

Torsion Mode > 30 Hz

Bending Mode> 41 Hz

Objective: Minimize Mass

There 230 design variables, which are assigned with upper bound and lower bound value as 3 mm and 0.6 mm. And by using above constraints and size variables, size optimization is carried out using optistruct, to attain the objective of minimizing the mass.

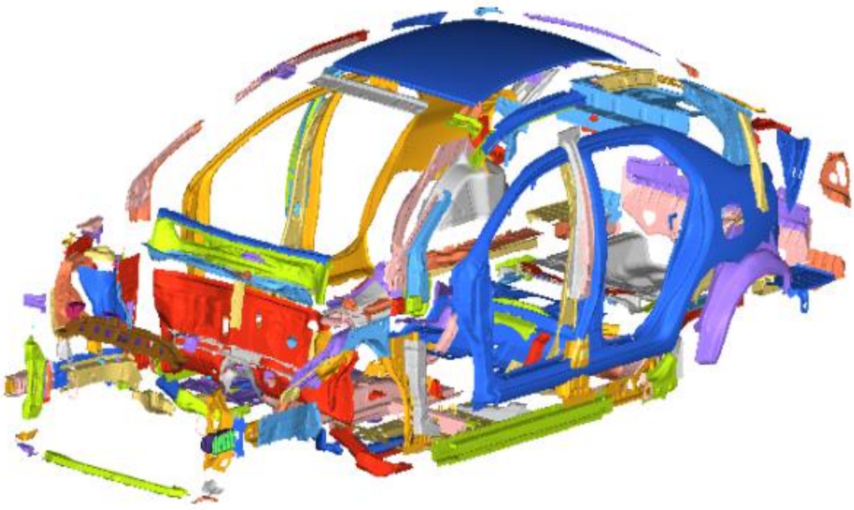

Figure 4.1 BIW - Size Variables in Exploded View

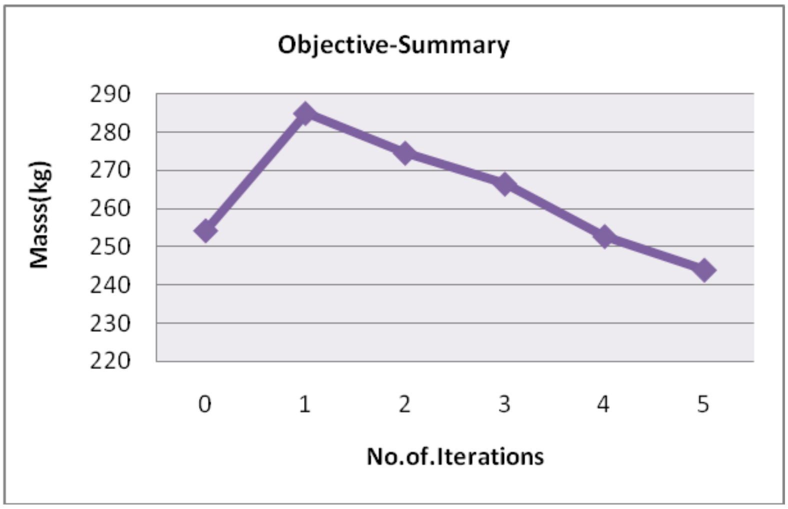

Figure 4.2 Mass Vs No. of Iterations

The above bar chart indicates the variation between mass (kg) in Y-axis and the number of iterations in X-axisFigure 4.3 and 4.4 shows static analysis of Bending and torsion baseline versus optimized contour plot. Figure 4.5 and 4.6 shows Modal analysis of Bending and torsion baseline versus optimized contour plot.

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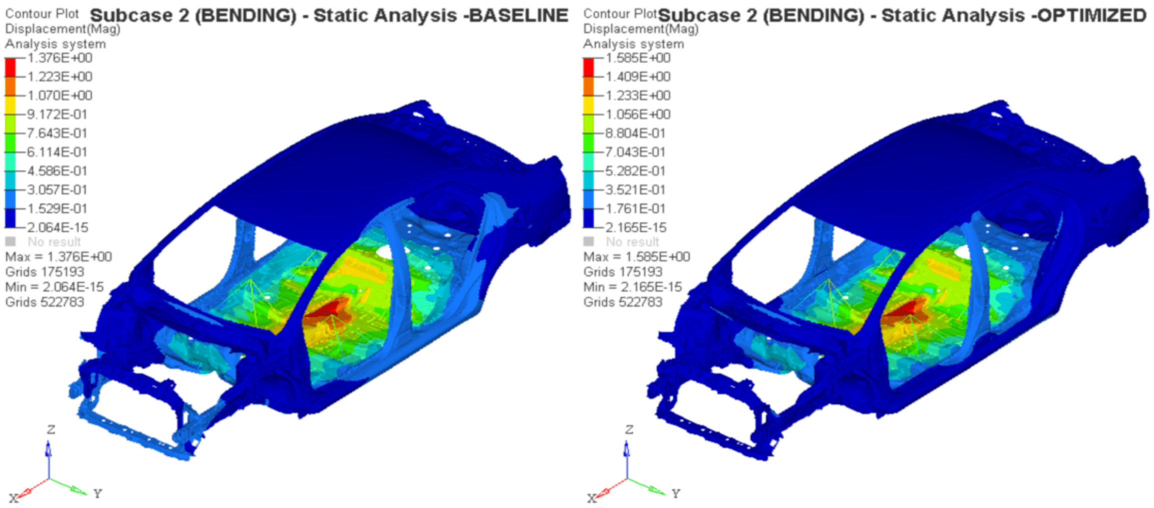

Figure 4.3 static Analysis - Bending Baseline Vs Optimized

Table 4.1Bending Stiffness summary

Description	Base Line Value	Optimized Value	Difference
Bending Stiffness - kN/mm	15	19.37	4.37

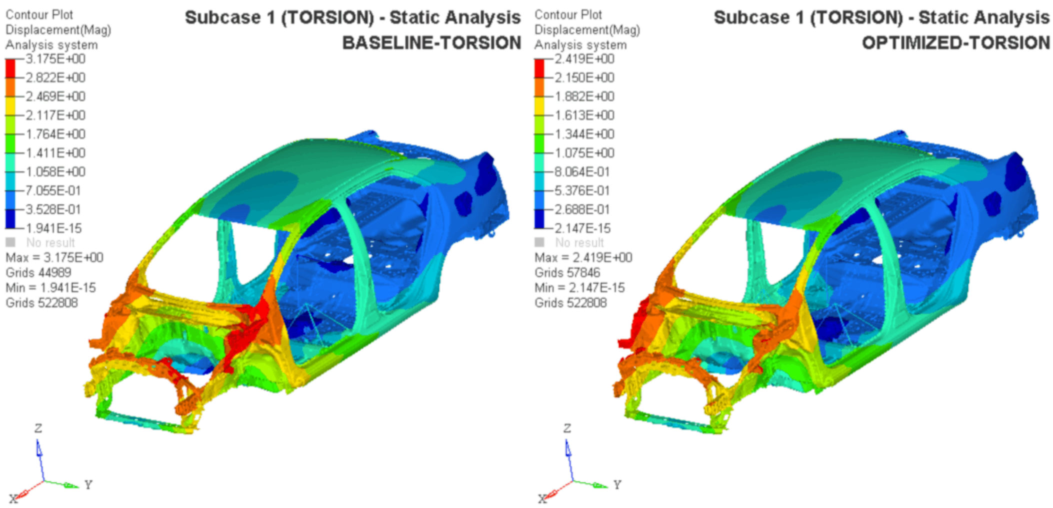

Figure4.4 static Analysis - Torsion Baseline Vs Optimized

Table 4.2Torsional Stiffness summary

Description	Base Line Value	Optimized Value	Difference
Torsional Stiffness - kNm/deg	7.98	8.9	0.92

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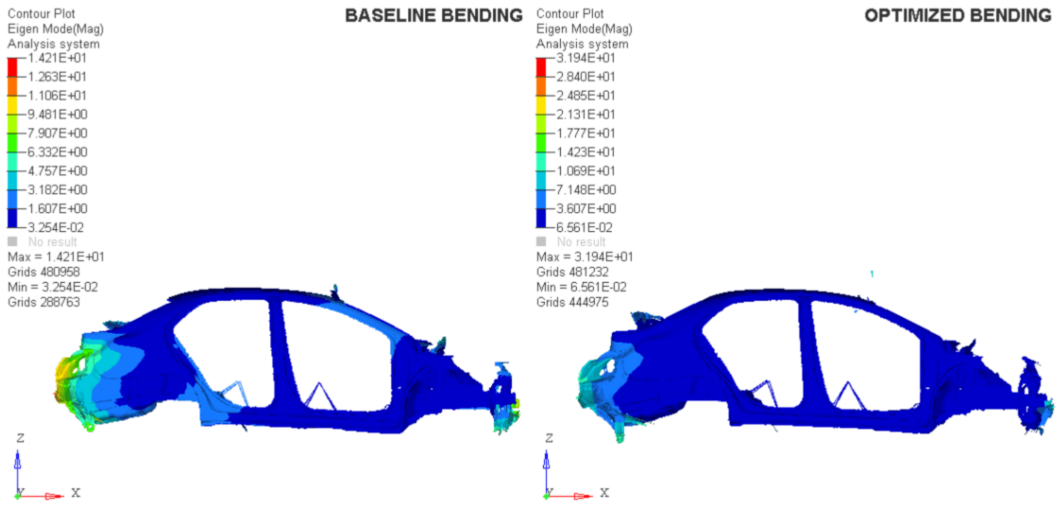

Figure 4.5 Modal Analysis - Bending Baseline Vs Optimized

Table 4.3Bending Frequency summary

Description	Base Line Value	Optimized Value	Difference
Bending Frequency (Hz)	41	45.3	4.3

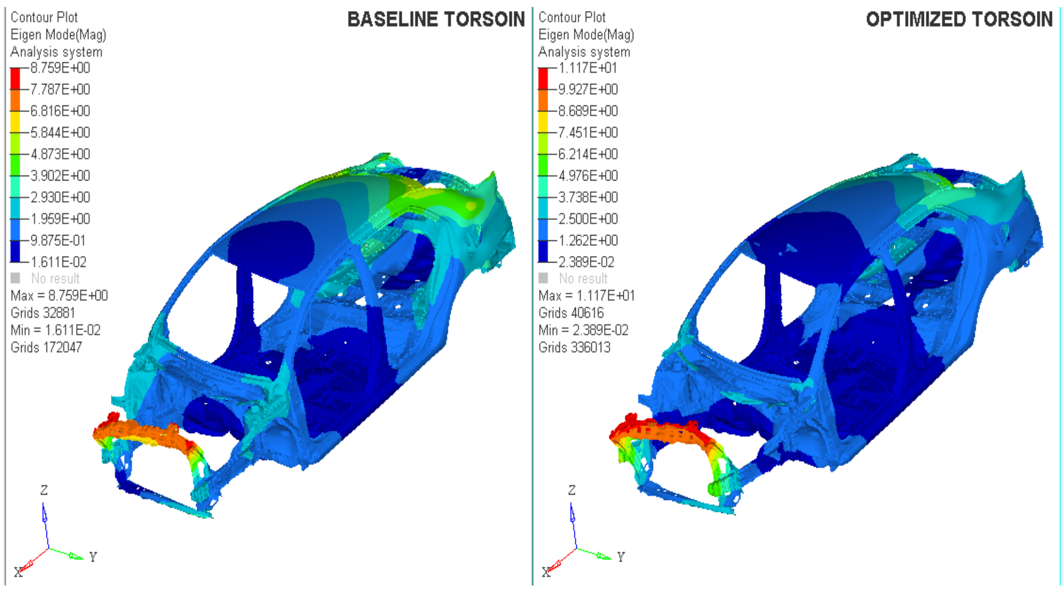

Figure 4.6 Modal Analysis - Torsion Baseline Vs Optimized

Table 4.4Torsional Frequency summary

Description	Base Line Value	Optimized Value	Difference
Torsional Frequency (Hz)	30	32.6	2.6

Table 4.5Result comparison of original and optimized model

	Base Line Value	Optimized Value	Difference
Mass – Kg	254	244	-10

V. CONCLUSION

The design objective of minimizing the mass was obtained by using size optimization. As a result of which, it is shown that reasonable improvements has beenattained for the torsion and bending modes natural frequencies. The BIW structure after the modification also shows significant changes in the static stiffness, within the limited constraints. Therefore, the size optimization yields a BIW structure with minimized mass to develop a fuel efficient car and with improved dynamic properties that has significant effect on the vibrationand crashworthiness of a car. Therefore, by improving the dynamic characteristics of BIW, problems and failures associated with resonance and fatigue can be prevented.

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