International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 01 | Jan 2021 www.irjet.net p-ISSN: 2395-0072

Optimization of Cross-Car Beam (CCB) a Sub-System of Automobile by Modal Analysis

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Abstract - *Computer Aided Engineering (CAE) plays an important role in automotive design. Modal performance of the Cross-Car Beam (CCB) sub-system has been studied in this article. CAD modelling is generated by using CATIA V5 and finite element software Hypermesh / OptiStruct has been used in modal analysis investigations. Post processing is carried out via Hyper-works. Initially in this analysismode shapes and natural frequencies of the Cross-Car Beam (CCB) of sub-system is calculated. Engineered modification has been applied to rise the inherent frequency. The result shows this method can effectively optimize the inherent frequency of the Cross-Car Beam (CCB) sub-system.*

Key Words: **CAE analysis, Cross Car Beam (CCB), Modal Analysis, Mode shape, Frequency.**

1. INTRODUCTION

To provide better comfort and satisfaction to the customers, automotive NVH requirement is getting higher and higher with the developing of automotive industry. Vibration of the key components in the car has a high contribution to the NVH performance of the whole vehicle.

Instrument panel (IP) is the largest inner trim parts which directly shown to the passengers, have not only beauty and function requirement but also NVH and safety request [1, 2].A cross-car beam (CCB) or an instrument panel (IP) support integrates the cross-car structure, steering column, air conditioning module and airbag system, electrical components, and plastic enclosure into one beam. Moreover, it plays a vital role in absorbing the energy of accidents. The vibration and noise on dashboard can be directly felt by passengers, which are transferred from CCB [Cross Car Bar] to BIW [Body in White] parts. Thus the modal analysis of Cross-Car Beam (CCB) sub-system plays an important role in NVH character of the wholevehicle[3].

CAE analysis is a very efficient way to study the NVH character. As it can help shorten the test cycle and reduce development cost, CAE analysis is widely used during automotive development procedure [5, 6]. Zhi-Kui MA etc. studied modal analysis basics of Instrumental panel [1]. Francesc Volart & Sergio Faria gives idea about modal analysis of cross car beam. It shows proper optimization method used for achieving target frequency [2]. Kiran Kumar Dama etc. studied modal analysis of an automotive sub-system [3]. Kim M.S. etc. studied the dynamic impact of passenger air-bag(PAB) module by using FEM to predict the dynamic characteristics of vehicle ride safety against head impact[7].Wang P etc. did an impact simulation tests for head and knee bolster as well as NVH analysis[8].

In this article, finite-element model (FE model) of Cross-Car Beam (CCB) sub-system is first set up based on 3D model in Hypermesh. After that, the complete FE model is created with FE parts assembled together and boundary conditions added on it. After that, the modal result is carried out by Hypermesh/ OptiStruct. Post processing of CCB is carried out by Hyperwork. Next to this some engineered modification is applied to the Cross-Car Beam (CCB) sub-system design to improve its modalcharacter

1.1 CAD Modeling

Based on the packaging dimensions CAD model of an automotive cross-car beam sub-system was developed using CATIA V5. Reference model would be used for the succeeding design and evaluation processes. Figure 1 shows the 3D model of the Cross-Car Beam (CCB) sub-system developed for this investigation.

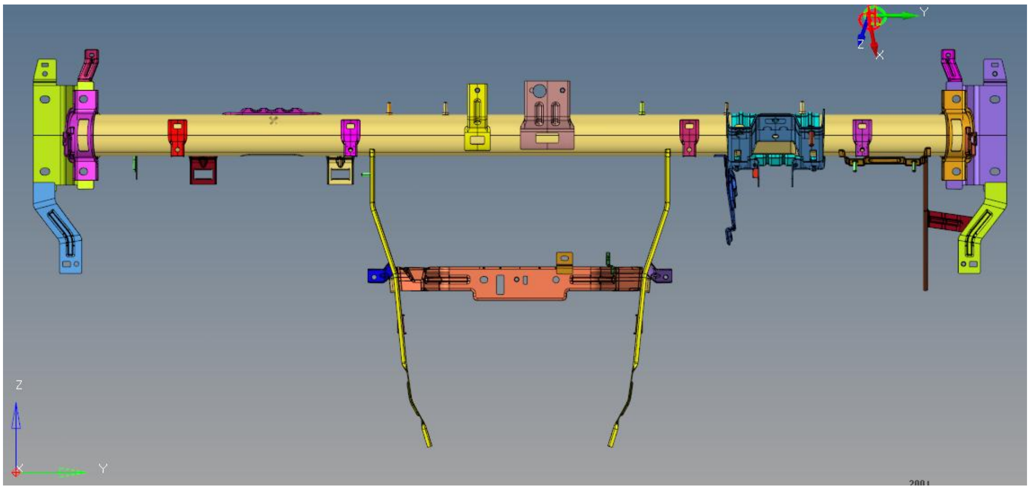

Fig -1: CAD Model of Cross-Car Beam Sub-System

1.2 Modelling and Boundary Condition:

Modelling: The Cross-Car Beam (CCB) sub-system developed for a multi-purpose vehicle is taken into modal analysis. Hypermesh is used to build up the FE model. Fig.1 shows the 3D model of the Cross-Car Beam (CCB) sub-system. The FE model is set up shown as fig.2 with shell element. It contains 43435 elements and 46108 nodes.

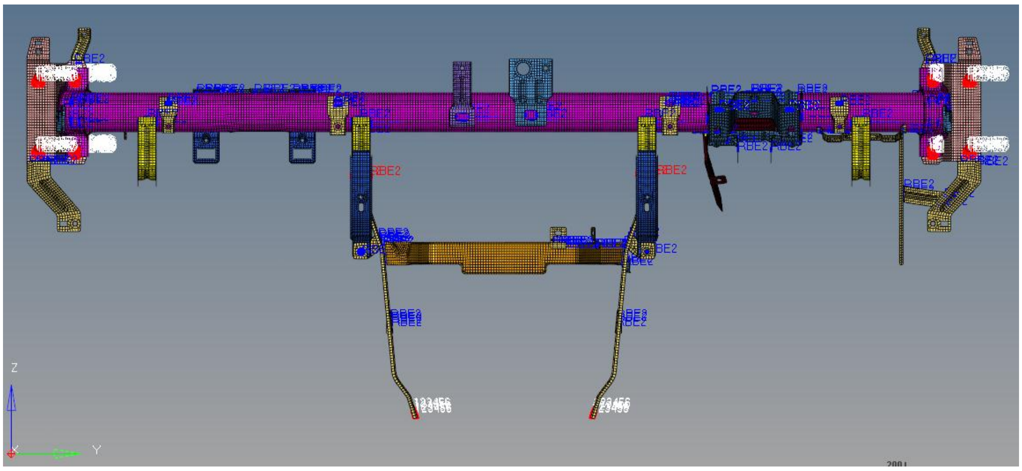

Fig -2: FE Model of Cross-Car Beam Sub-System

The Finite Element (FE) modeling of the Cross-Car Beam (CCB) Sub-System is developed by HyperMesh. The average element size of 5mm is used to this Finite Element Mesh. In this process the mid surfaces of the parts are extracted and meshed with combination of Quad and Tria elements (i.e., mixed elements) [5].

Table -1: Quality Criteria of FE Modeling (For 2D)

Warpage	<	10°
Jacobian	>	0.6
Aspect Ratio	<	5
Maximum Angle of Quads	=	135
Minimum Angle of Quads	=	45
Maximum Angle of Trias	=	120

Minimum Angle of Trias	=	20
% of Trias	<	5%

Some necessary simplifications are made to help made the analysis more efficiently. Bolt joint are simplified as REB2 rigid link which is shown as fig 3.

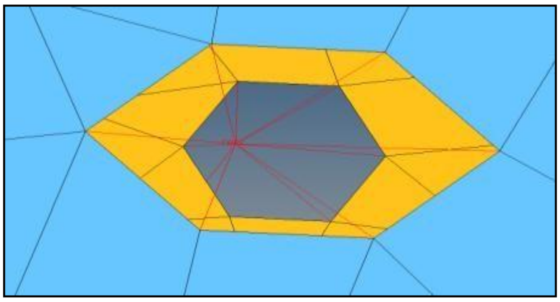

Fig -3: REB2 connection

Most of the Brackets are connected to each other by welding, represented by RBE2 connection. These welding are treated as rigid connection which is shown in Fig 3.

Materials: Most of the Cross-Car Beam parts are made by steel. In light weight case are available in other materials like magnesium, aluminium. But there are also some other materials are used in this Cross-Car Beam Sub-System. Some brackets are made by IFHS [Interstitial Free High Strength], which is cold rolled and annealed interstitial free high strength steel. Materials properties are shown in Tab2.

Table -2: Materials property

Materials	**Young 's modulus (GPa)**	**Poisson's ratio**	**Density (kg/mm3)**
Steel	200	0.3	7.85 e-6
IFHS	207	0.3	7.83 e-9

Boundary conditions: The Cross-Car Beam (CCB) is fixed on BIW (Body in white). CCB is fixed at both ends as well as front side. These CCB is fixed at 10 locations. These constrains are shown in Fig 4. Fixed constraints are applied on these nodes to fix all six degrees of freedom in CAE software.

Figure 4 shows the Finite Element (FE) Model of Cross-Car Beam Sub-System with constraints.

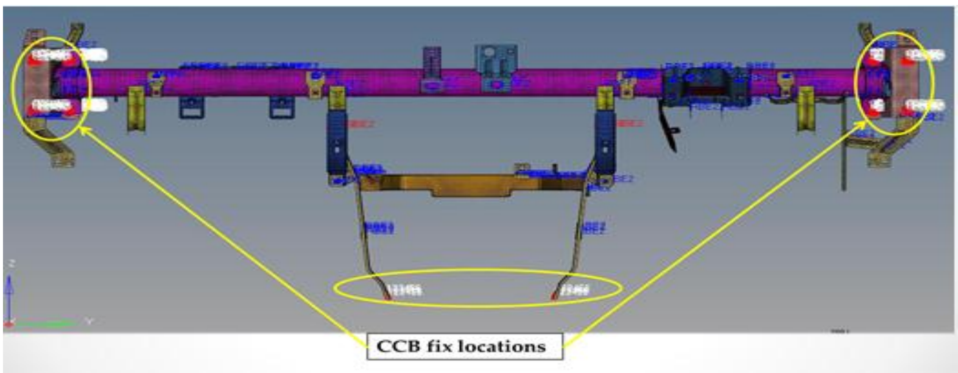

Fig -4: Constraints

2. Modal Analysis Request and Method

The engine in this vehicle has four cylinders. The idle frequency of a four cylinder engine is 25HZ.Automotive components are usually designed to have different inherent frequency in order not to resonate with engine. For instrument panel, its inherent frequency should be designed higher than 25HZ. For CCB, its inherent frequency should be designed higher than 45HZ.

Modal analysis is a technique used to calculate the vibration shapes and associated frequencies that a structure will exhibit. The equilibrium equation for a structure performing free vibration appears as the eigenvalue problem:

$$[K - \lambda M]x = 0 \qquad (1)$$

Where, K is the stiffness matrix of the structure and M is the mass matrix. Damping is neglected in this calculation. The solution of the eigen value problem yields n eigen values λ, where n is the number of degrees-of-freedom. The vector is the eigenvector corresponding to the eigen value.

The Natural frequency fi follows directly from the Eigen value $f_i = \frac{\sqrt{\lambda}}{2\pi}$

(2)

The eigen value problem is solved using Lanczos. Simulation job is done by Hyper Mesh/OptiStruct.

3. Results

Three modal analyses are conducted to study dynamic frequency responses and mode shapes at fixed boundary conditions.

Figure 5, 6, 8 shows the mode shapes for the developed model with the fixed boundary conditions.

A) MBFM bracket with 1.2mm thickness

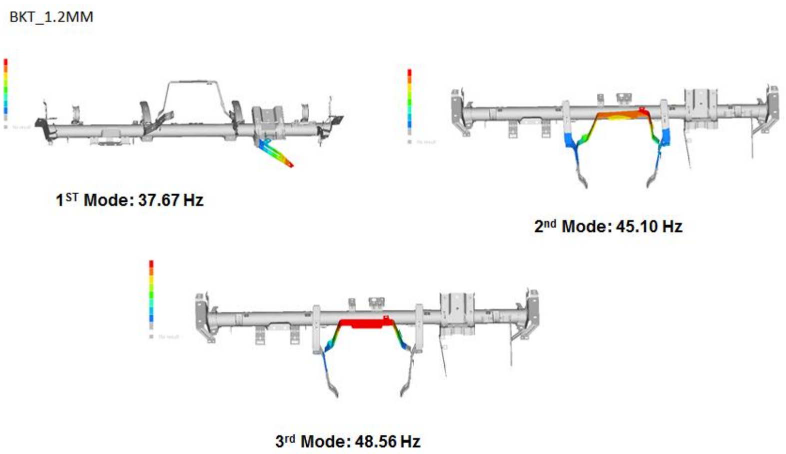

Fig- 5: Mode Shapes with frequency

Modal results are ready from the result file. Tab3 shows the first three orders of modal. The vibration shapes are shown in Fig 5.

Tab -3: Modal frequency

Order	Frequency (Hz)
1	37.67
2	45.10
3	48.56

From the result, the first order mode shape observed on MBFM bracket with 37.67HZ frequency. The second order mode shape shows on HVAC bracket with 45.10HZ frequency.

The vibration of the sub system will occur on the MBFM bracket and HVAC bracket. Which means this area is a weak area that easy to cause resonance. Some engineered modification work is done to help the first order frequency of the CCB larger than 45Hz which helps to the first frequency of the instrumental panel larger than 25HZ.

B) Modified MBFM bracket with 1.6mm thickness:

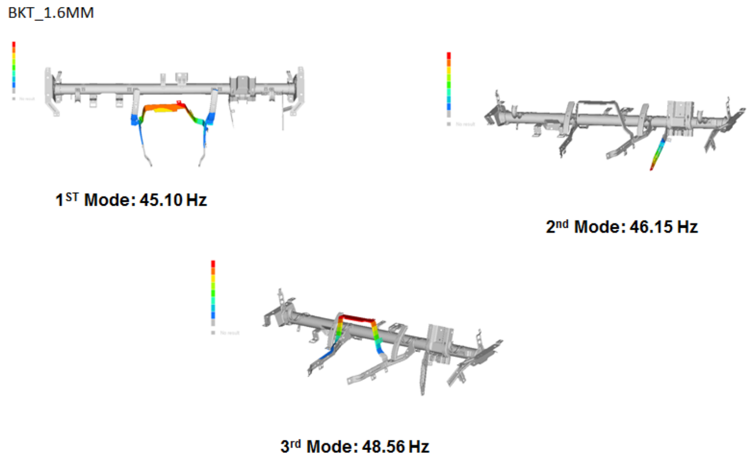

Fig -6: Mode Shapes with frequency

Tab -4: Modal frequency

Order	Frequency (Hz)
1	45.10
2	46.15
3	48.56

Another modification is to create retain flanges in HVAC bracket at the weak area as shown in Fig 7. This will increase the local stiffness on that weak area and help change the natural frequency of the component to avoid resonance.

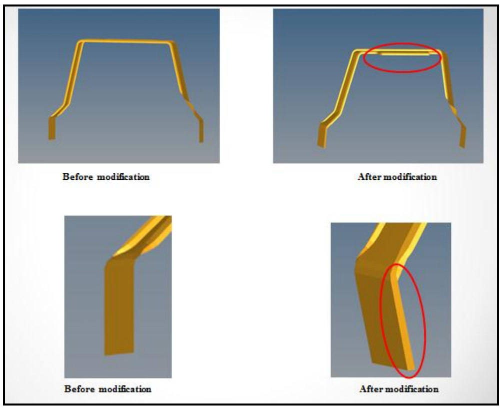

Fig -7: Design Modification

C) Modified CCB with Retain Flange on HVAC Front Mounting Bracket with 1.6mm thickness:

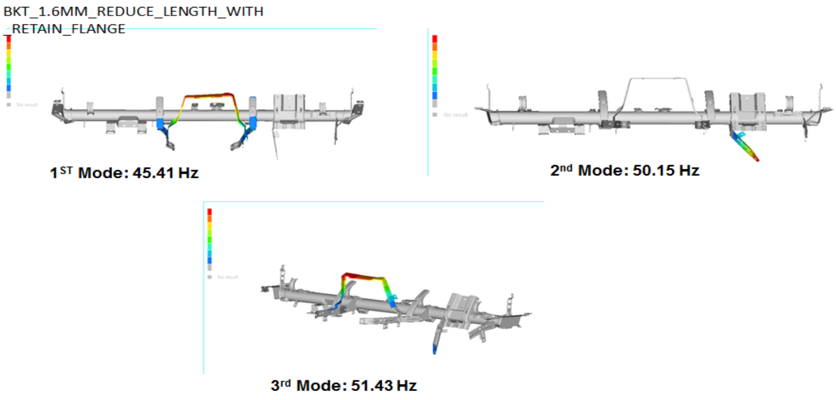

Fig -8: Mode Shapes with frequency

Tab -5: Modal frequency

Order	**Frequency (Hz)**
1	45.41
2	50.15
3	51.43

The first order vibration frequency rises from 37.67Hz to 45.41Hz. After modification which meet the design requirement. The significant change in the first order frequency is observed compare with the original modal.

From the vibration shape photograph shown in Fig 8, the second order modal frequency is 50.15HZ and third order modal frequency is 51.43HZ.

The comparison of natural frequency in existing and modified model is shown in Tab 6.

Tab- 6: Frequency comparison of existing and modified model.

Design Change	1st Frequency Mode (Hz)	2nd Frequency Mode (Hz)	3rd Frequency Mode (Hz)
MBFM bracket with 1.2mm thickness	37.67	45.10	48.56
MBFM bracket with 1.6mm thickness	45.10	46.15	48.56
Retain Flange on HVAC Front Mounting Bracket with 1.6mm thickness	45.41	50.15	51.43

4. CONCLUSIONS

Modal analysis has been done to optimize Cross Car Beam (CCB). Modal frequency has been calculated and vibration shape has been carried out in this paper. Engineered modification has been made on Cross car beam (CCB) model to avoid resonate with engine.

Existing model having different frequency mode shape occurs such as 37.67Hz, 45.10Hz&48.56Hz, which is lower frequency mode shape as compare to modified model frequency mode shape 45.41Hz, 50.15Hz&51.43Hz respectively. The result Tab5.Shows this modification can rise the inherent frequency effectively.

This article also includes basics of modal analysis method. This method can save time and improve efficiency during automotive components development process.

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