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MULTI-OBJECTIVE MOUNT BRACKET OPTIMIZATION OF A COMMERCIAL VEHICLE

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ABSTRACT

Automotive industry is rapidly developing and progressing in every aspect. Fuel efficiency, durability, performance and customer comforts are very challenging areas and customer expectations are increasing continuously. Improving the vehicle in every aspect is almost impossible at same time therefore vehicle attributes must compensate at some level of engineering and agree on most convenient design.

Most simple way of increasing fuel efficiency is to decrease weight of vehicle and this also contribute performance improvement but at the other hand weight reduction is oppositely decrease durability performance of vehicle and additionally noise and deeply vibration characteristics of vehicle decrease.

Best way to agree on most convenient design is optimizing it wisely. At this stage, this paper investigates engine mount design in terms of weight, vibration and durability perspectives.

Weight reduction of mount brackets contributes vehicle performance and fuel efficiency but decrease the vibration characteristics and durability. Thus, it is vitally important to obtain most convenient design in all aspects.

At initial packages studies, mount brackets design completes roughly just for package perspective. Then all attributes teams start to work on it separately, but this separate working end up with confusion on design and this can cause delays on projects due to each team works only their own perspective. Thus, optimization of this design in every aspect is very important not only obtain most convenient design but also prevent projects delays and additional costs.

NOMENCLATURE

x	=	*variable*
f(x)	=	*function*
g(x),h(x)	=	*equality or inequality constraints function*
m ,n	=	*maximum number*
I ,j	=	*generic index number*
CAD	=	*Computer aided design*
CAE	=	*Computer aided engineering*
3D	=	*Three dimension*

INTRODUCTION

Engine mounts has two main duty for vehicle: first, it is main component that connect engine to vehicle chassis carry on whole engine weight thus mount bracket must design as robust to carry on engine weight. Secondly, engine is the source of power and generates severe

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vibrations and these vibrations directly transmit to vehicle chassis and then to the passenger seats and vehicle interiors. Thus, mount as a component must decrease these vibrations as possible as it can be to increase passenger comfort.
This paper investigates mount bracket design to obtain most convenient design for durability, vibration and weight. Finite element model of brackets are modeled by using Hypermesh, mesh processor and optimization of design solved by Optistruct software. Results are compared by weight, stress and vibration levels.
Below picture shows the mount bracket initial design that is investigated. Brackets were modeled from preliminary CAD models.

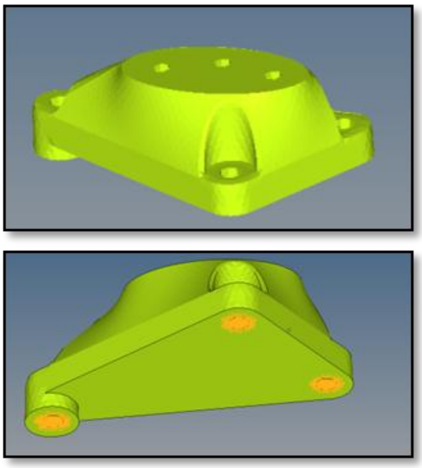

Figure1: Preliminary design of mount bracket

At initial phase of vehicle, mount is designed only generally and roughly for package purpose. This design will be investigated by vibration and stress to minimize weight. There are lots of limitations that this optimization should provide.
Constraints:

- Mount bracket should be at min weight
- Mount bracket minimize the vibration level
- Mount bracket stress value must be minimum
- Mount bracket should carry engine payload as expected
- Mount design must be inside package limits

Those constraints make the design optimization problem multi-objective as it must perform multiple criteria and optimization solution makes it topology optimization because initial mount block will be investigated by removing volume.
Additionally, the optimization is investigating the problem as multi-disciplinary hence vibration, stress and weight criteria in terms on its natural perspectives.

MATHEMATICAL OPTIMIZATION

The basic principle of optimization is to find the best possible solution under given circumstances. The objective of the optimization problem is often some sort of maximization or minimization, for example minimization of required time or maximization of stiffness. To be able to find the optimum solution depending on a set of design variables needs to be expressed with a numerical value. This is typically done with a function of the design variables known as the cost function which defines the limitations and the goal.
Mathematically the general optimization problem is most often formulated as minimization of the cost function (which can easily be transformed to maximization by minimizing the negative function) subject to constraints, this can be expressed as:

$$Find\ x = \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}\ which\ minimize\ f(x)$$

For current optimizations, functions:

$$g(x) = x_1 \leq 1300\ g$$

$$h(x) = x_2 \leq 120\ MPa$$

$$k(x) = x_3(compliance) \leq target\ value$$

$$l(x) = x_4(design) \leq design\ package$$

Wherex is the vector of design parameters and f(x) is the cost function. The functionsg(x), h(x),$k(x)$ and $l(x)$are named as inequality constraint function respectively and theydefine the constraints of the problem. This is called a constrained optimization problem. Where $x_1$refer mass of mount,x_2 refer max stress of mount,x_3 refer compliance and $x_4$refers the design as volume.
CAE programs are very convenient to use and makes very quick the manufacturing process by contributing the fast design and fast solution to direct design. Mount designed with using 3D design software CATIA and modeled by using Hypermesh finite elements and topology optimization performed by using Optistruct software.

The possible difficulties for results are:

- If the mount stress is to high due to payloads design package can limit the outer volume
- If vibration target could not satisfy, weight or outer surface can increase
- Due to weight increasement, performance target could not be satisfied

Possible difficulties come occur while working on this project:

- Design of mount due to the limitation and after topology results, design also should satisfy in terms of manufacturing perspective
- Solution of topology optimization must be completed by powerful computers; computer limitation can cause premature topology results, nonconvergent or failures.

TOPOLOGY OPTIMIZATION

Optimization methods for structures, mainly distinguish with each other by the nature of them. These are: size, shape and topology optimization. Three optimization methods correspond to the three stages of the product design process, namely the detailed design, basic design and conceptual design [Po, W, 2016].
Size optimization keeps the structural shape and topology structure invariant, to optimize the various parameters of structure, such as thickness, section size of beam, materials' properties; shape optimization maintains the topology structure, to change the boundary of structure and shape, seek the most convenient structure boundary situation and shape; topology optimization is to purpose the optimal path of materials' distribution in a continuousdomain which meet the displacement and stress conditions in structure, make a certain performance trade off.

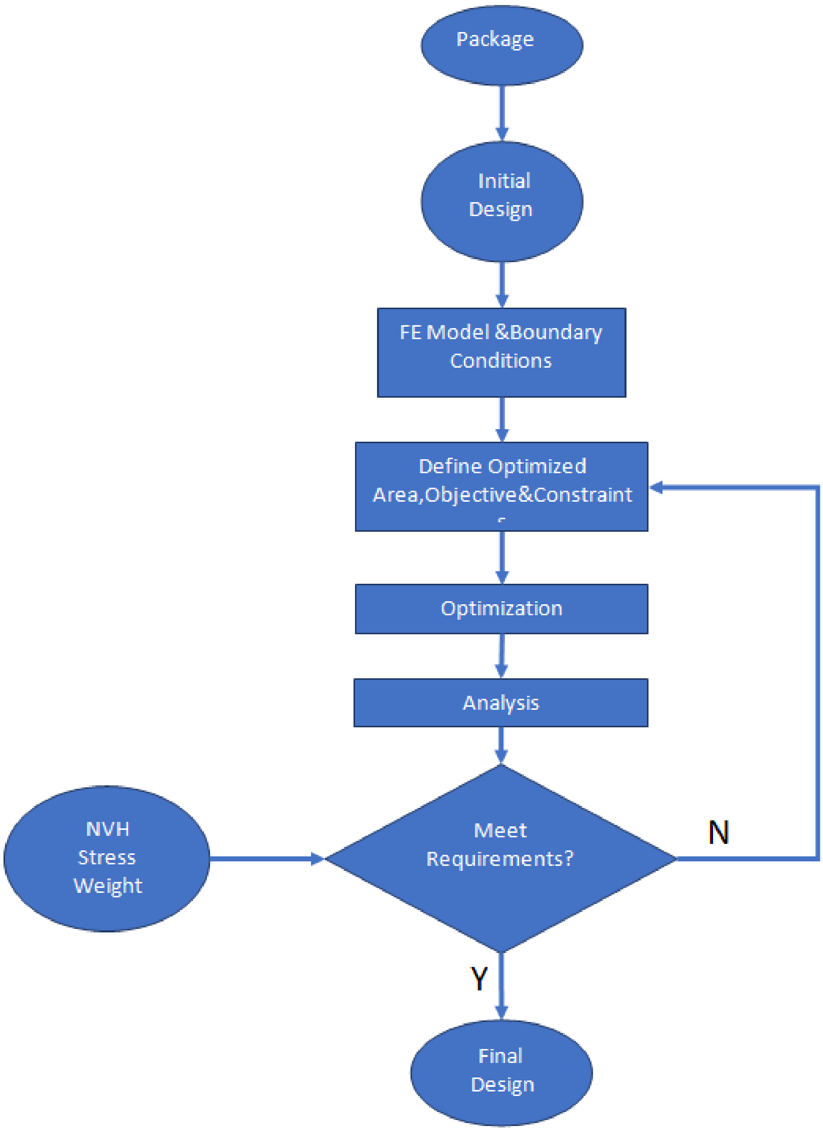

Figure 2: Design process of mount

Thus, compared to size and shape optimization, topology optimization with more freedom degree and greater design space, its greatest feature is under uncertain structural shape, according to the known boundary condition and a given load to determine the reasonable structure, both for the conceptual design of new products and improvement design for existing products, it is the most promising aspect of structural optimization [Po, W, 2016].
Evolutionary structural optimization method believes that stress in any parts of the structure should under the same level in an ideal structure. That means the local material with a low stress state is not fully utilized, so you can delete the material artificially. So gradually remove material which in a low stress state, and then delete the update rate, so optimizedstructure becomes more uniform [Po, W, 2016].

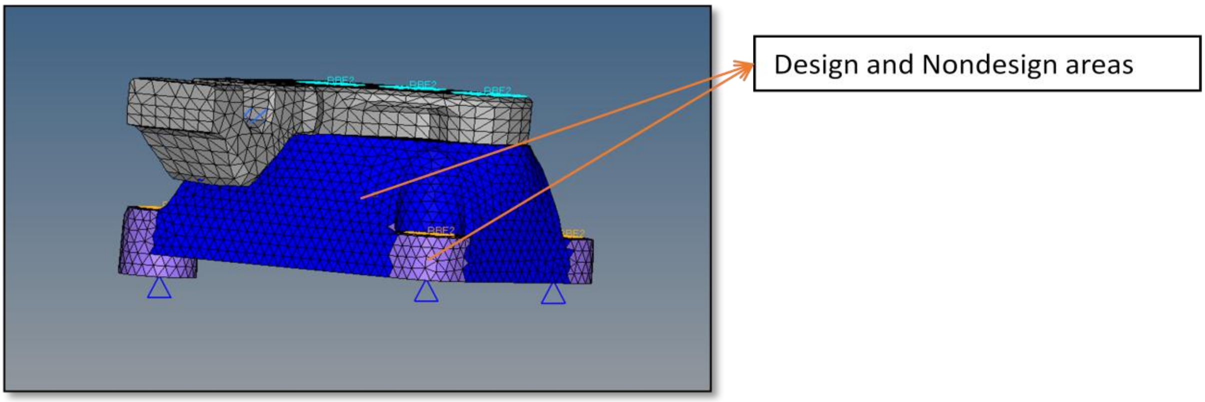

Figure3: Mount bracket optimization design and nondesign areas

Mainly four analyses are performed to obtain optimum design.First, mount will be evaluated in terms of stress with using topology analysis then bracket will be redesigned then modal analysis and frequency response analysis will be performed to observe natural frequency of mount bracket if the criteria met both vibration and stress levels, design will be minimized in terms of weight otherwise iterations will be performed until to meet criteria.

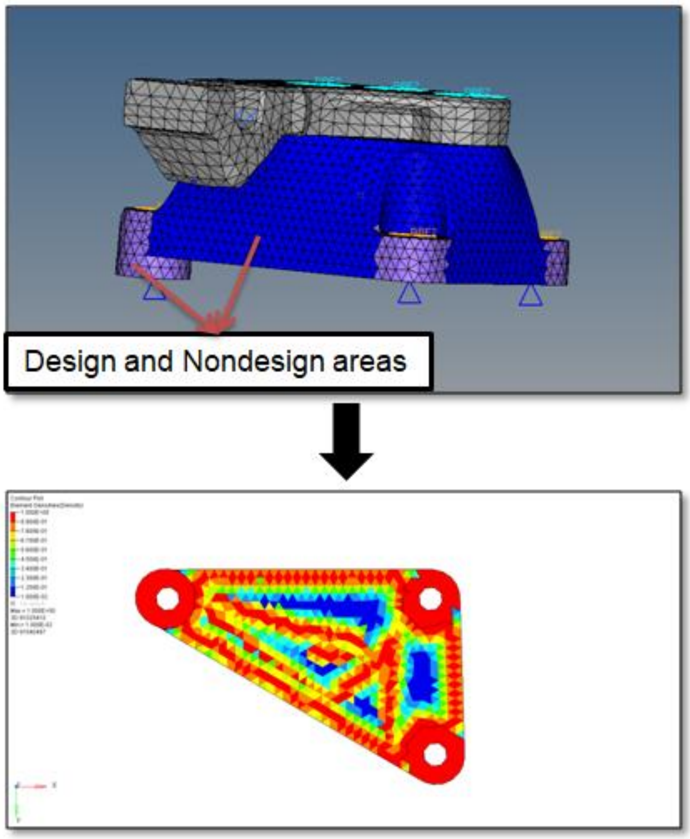

Figure4: Optimization output

- Analysis methods:
- Topology analysis(Stress analysis)
- Modal analysis
- Frequency response analysis
- Compliance Analysis

Modal analysis is used to understand the natural frequency of system and mount bracket.According to results, if there is match between modes or if natural frequencies are close to each other to excite adjacent component to resonance situation, design modifications must be done to decrease vibration levels and to prevent resonance situation.
Frequency response analysis is performed to understand eigenvalues of multi component systems such as engine. It gives exact component eigenvalues on a system.
Stress analysis is conducted on bracket only to understand maximum stress levels on bracket and accordingly topology optimization results.
Topology analysis is performed simultaneously with stress analysis to decrease mount weight as possible as it can by the time satisfying stress criteria.
As it can be observed all analysis has to be done and satisfy each target to obtain robust and optimum design for all aspects.

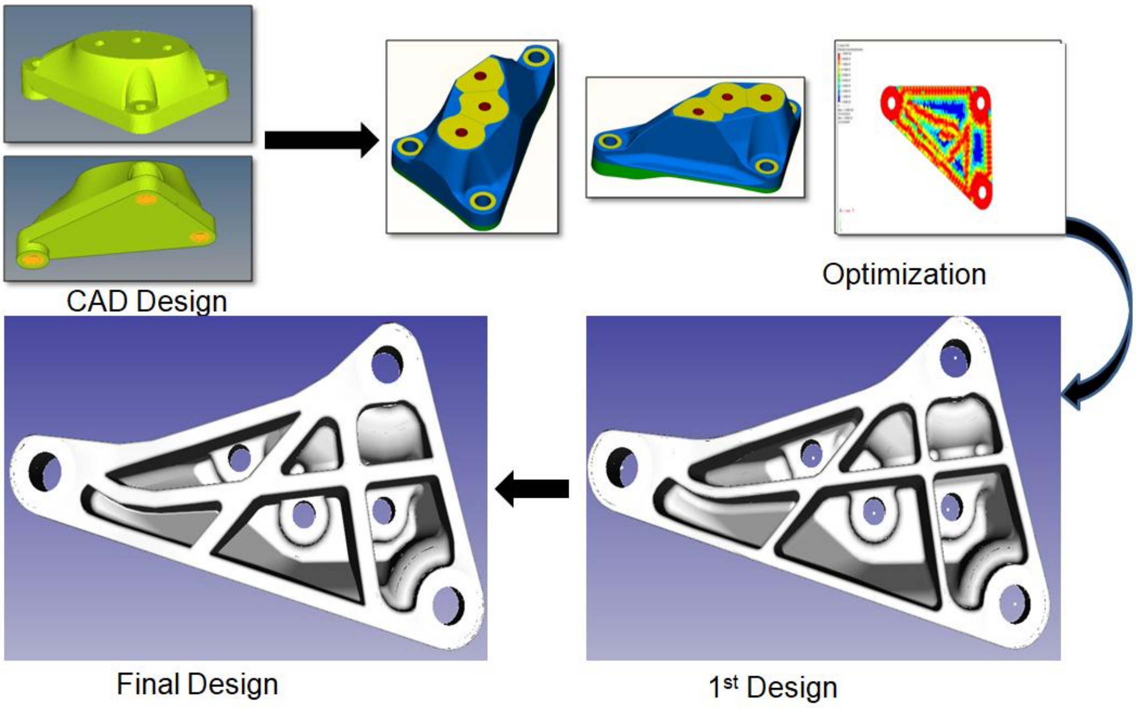

Figure 5: Optimization process from initial design to last design

MOUNT WEIGHT

At initial design case mount bracket weight is calculated by CAD program and it is 1.3 kg but after optimization and redesign of mount bracket, the weight is decreased 700 g and last design weight calculated as 600 g which is quite good according to initial design. Initial and last design of mount can be seen on figure 5.

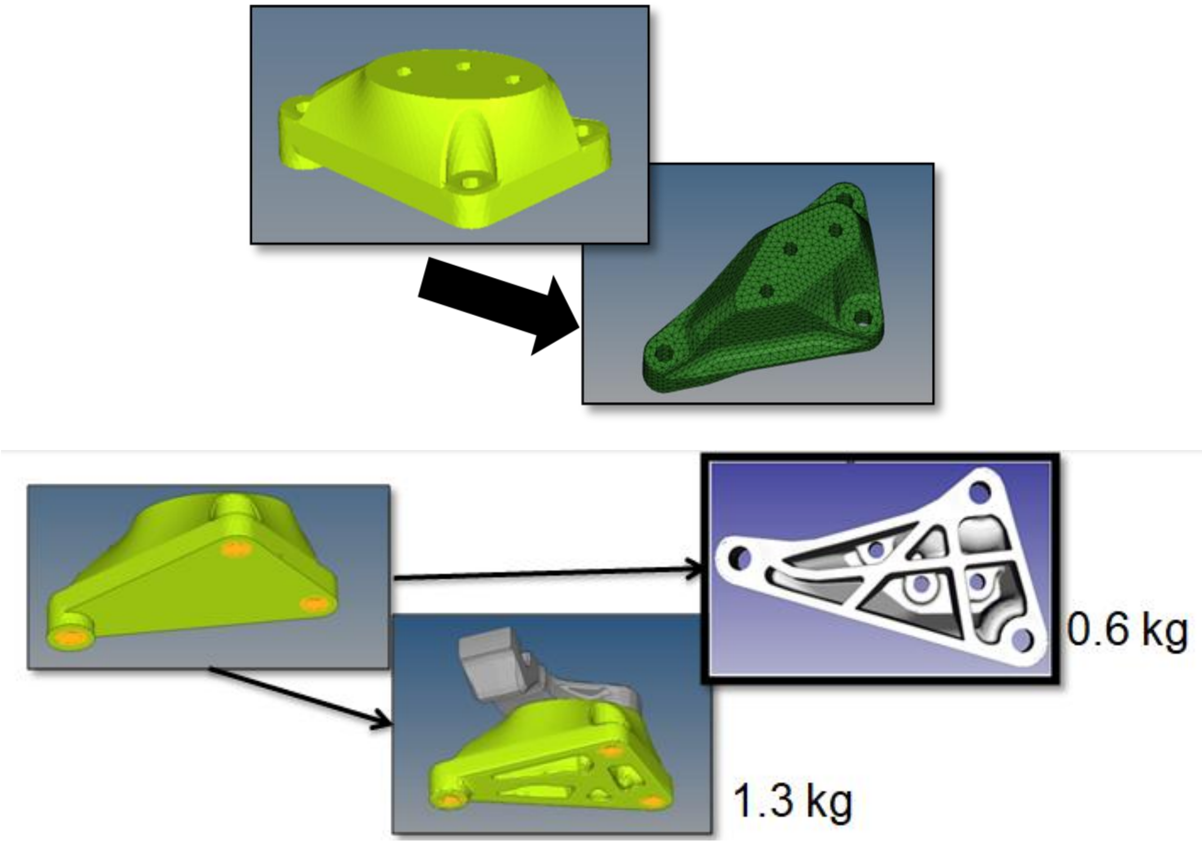

Figure 6: Initial and last design of mount bracket in terms of weight

This weight reduction provide vehicle weight reduction and thus fuel economy will improve and as considering that vehicle will be driven thousand kilometers, the weight reduction becomes very important.

FREQUENCY RESPONSE ANALYSIS

Frequency response analysis of mount shows the natural frequencies of part and decreasing amplitude is important if any components frequency overlays, it can cause resonance which can cause damage on components and severe vibrations. For that purpose frequency response analysis performed for mount for 3 directions and the amplitude decreased with design modifications. It is present on figure 7, the initial amplitudes were quite high but after optimization and design improvements the values decreased.

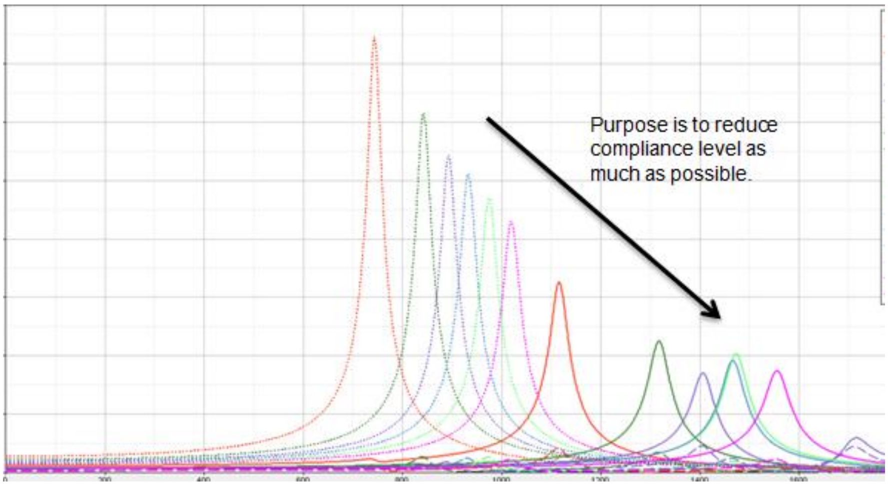

Figure 7: Mount frequency response analysis result for 3 directions

Since it is performed for specific frequency range X direction amplitudes remain almost same but shifted in frequency value that is also good contribution for design safety.

COMPLIANCE ANALYSIS

Compliance analysis shows the component reaction for unit loading for frequency range and it is one of the critic investigations for vibration analysis.
The straight line on figures below shows generic target for vehicle and it is aimed to decrease the amplitudes below that line but it may not be possible for every powertrain mount system. In this study after optimization study ,mount ribs may changed to decrease the compliance but as it can be seen on figure 8,9 and 10 the amplitudes are over the target at some frequency range which is not desirable but acceptable if these frequencies are not overlay with other components working range.

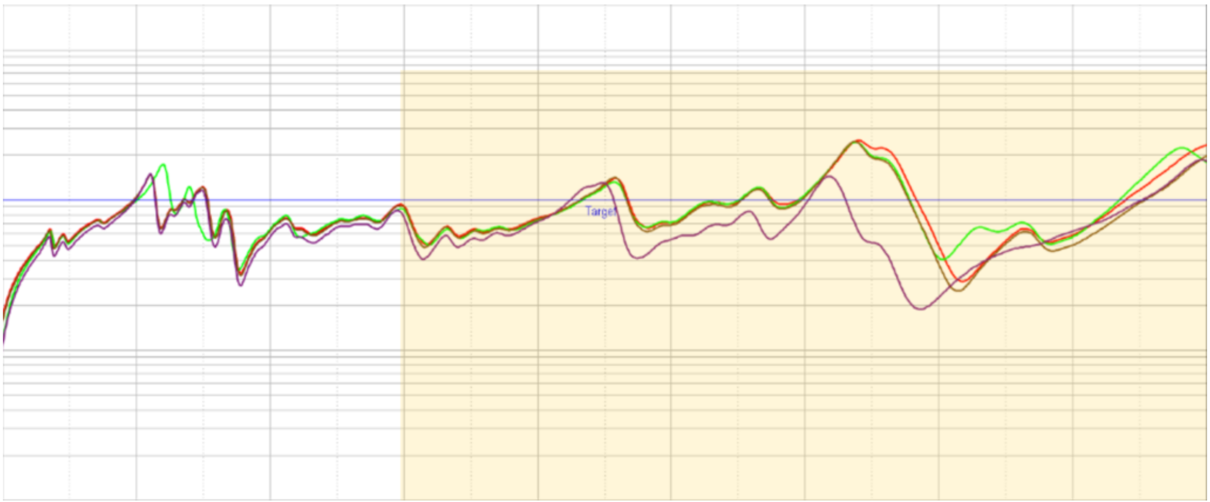

Figure 8: Mount compliance analysis result for X direction

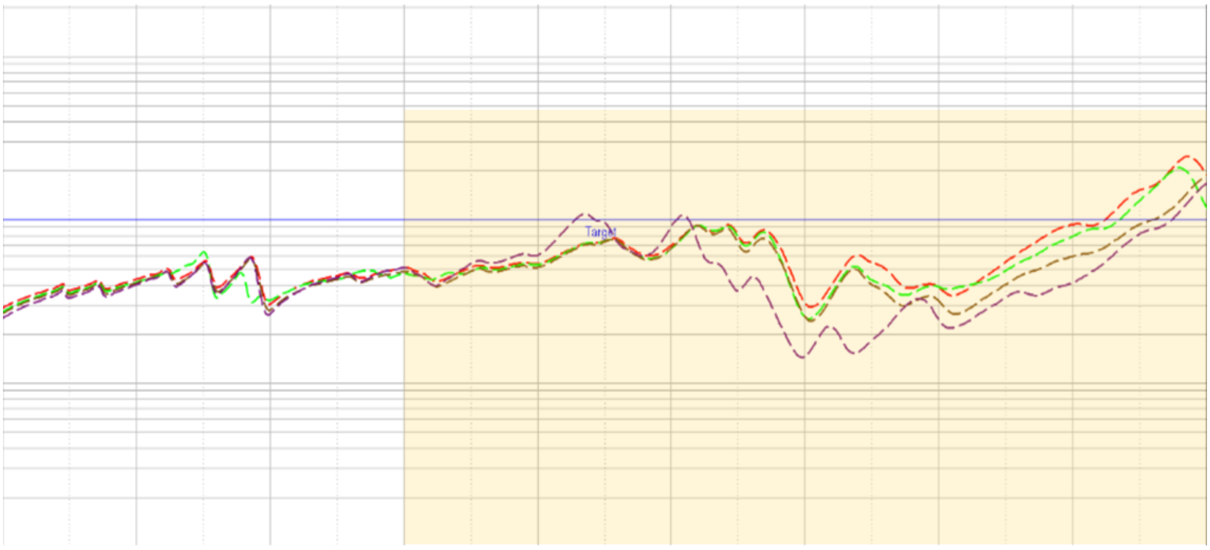

Figure 9: Mount compliance analysis result for Y direction

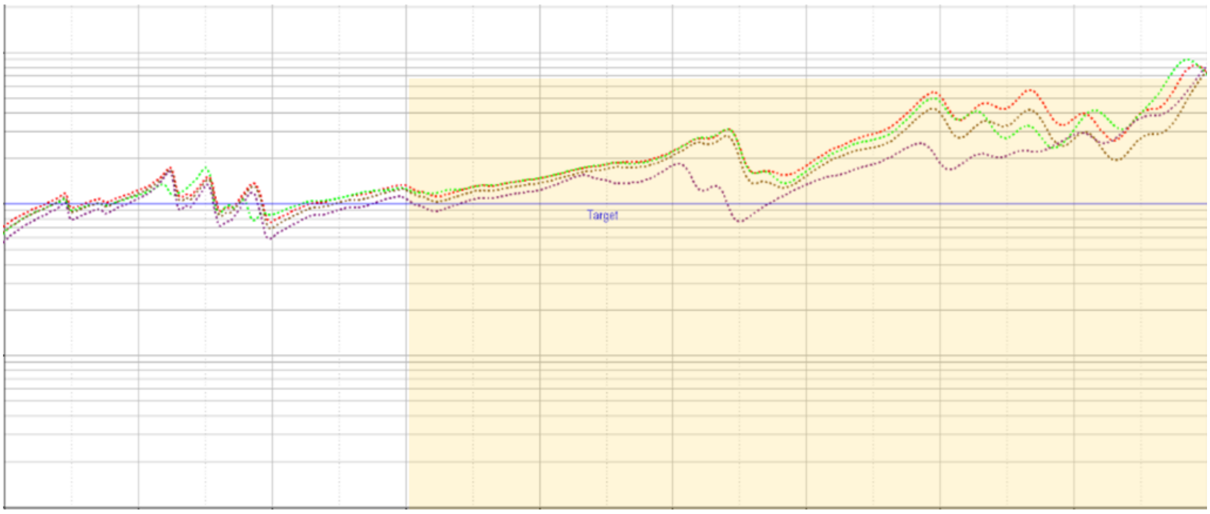

Figure 10: Mount compliance analysis result for Z direction

As it can be seen at figure 10, Z direction amplitudes are over the generic target at initial RPM and also frequency range which is not desirable. Thus final design was not acceptable for Z direction, so it is decided to compare the amplitudes for specific frequency range with comparator most similar vehicle mount. Figure 11 shows this comparison and it is clear that previous vehicle mount is also above the target and current mount has almost same amplitudes but lower than previous. Thus this design can be acceptable according to previous design. Only concern is even tough previous design higher than current, it is very short frequency range according to current.

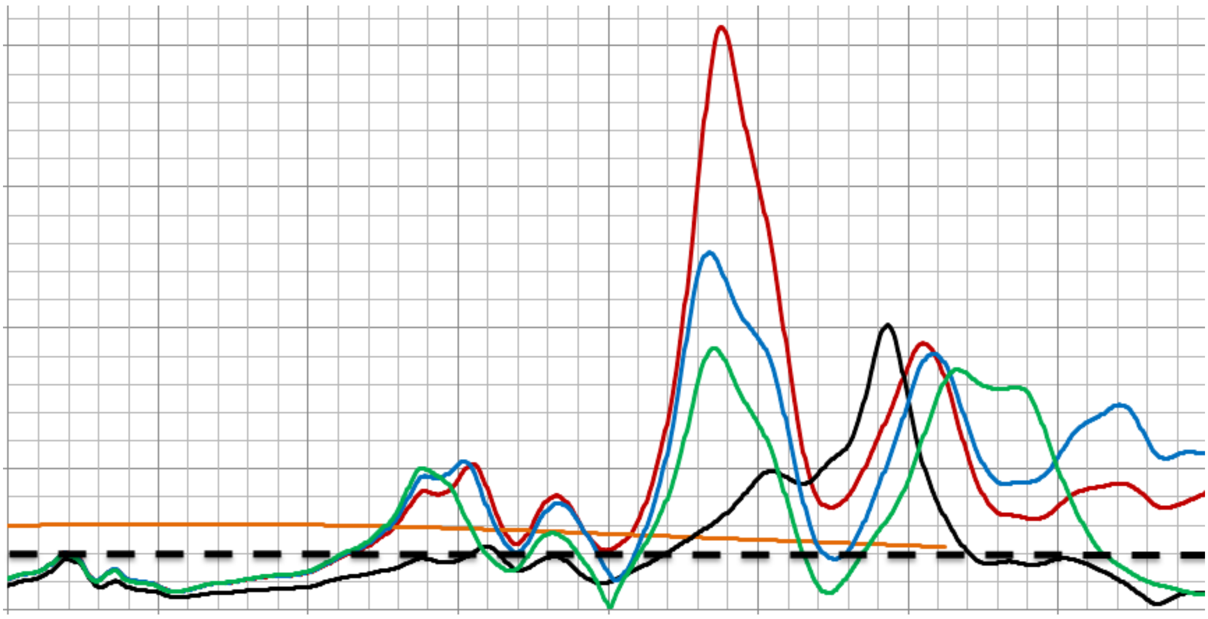

Figure11: Mount compliance analysis result comparison with comparator vehicle

CONCLUSION

Mount bracket is very critical component for powertrain and engine since it holds engine for durability and additionally decrease vibration of engine for engine working range and prevent thesevibration as not transmitting it to vehicle chassis, body and passengers. Since it is multi functional component thus the design of mount investigated for that purpose.

Initial mount design was designed as package purpose and it is designed according to package requirements. Each component has also weight target thus mount weight is decreased with optimization studies from 1300 g to 600 g which is very good improvement in terms of weight and fuel economy.

Mount optimization performed according to stress requirement and this optimization study defined the design ribs and removed unnecessary volumes. According to this study mount design investigated for mount frequency and mount compliance which is very important for vibration.

After optimization study, the mount compliance is decreased to desired range. Only the Z direction amplitudes are over the target which is not acceptable according to generic target but it is acceptable according to previous comparator vehicle mount.

References

Po, W., Qihua, M., Yiping, L. and Chao, T. “Topology Optimization Design of Automotive Engine Bracket”Energy and Power Engineering, 2016, 8, 230-235,2016.