Topology Optimization of Engine Structure of a Scooter Engine using OptiStruct

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Abbreviations: 3D: Three Dimensional  
MBD: Multi Body Dynamic  
CCL: Crank Case Left  
FEM: Finite Element Method  
RPM: Revolution per Minute  
CCR: Crank Case Right

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Abstract

An existing design of crank case assembly of a scooter engine is analyzed using OptiStruct with an objective to reduce the weight. Since the crank cases forms the heaviest part of the scooter engine and thus most critical component in order to reduce the overall engine weight, for it can help in improving engine performance, power to weight ratio and eventually fuel efficiency.

Here the crank case assembly houses the engine & transmission and forms a link between chassis & rear wheel and consequently subjected to various loads viz. combustion, transmission, mounting, suspension and road loads. Therefore, any design change requires a thorough analysis. In this study MotionView & MotionSolve are used to evaluate the dynamic loads viz: suspension, mounting and tyre axle loads.

The optimized design is taken for the final design of the engine. Thus, substantial weight reduction is achieved based on this study with passing the safety criteria as well as saving time spent in creating design iterations.

Introduction

In recent years, with increased demand for low fuel consumption and low cost vehicles, the light weight designs are highest priority during engine development stage in automobile industry. Additionally, increasing aggressive competition has forced all industries to reduce time to market significantly resulting accelerated changes in production and development. In light of the constraints of developing light weight vehicle meeting the tight schedules, demands for state-of-the-art product developments are stronger than ever.

To meet these demands, computer aided engineering (CAE) have been utilized significantly and have gained importance [1]. Almost all the vehicle manufacturing companies are now extensively using simulation tools to predict accurate design behavior during virtual validation stage. Here the product is analyzed in detail and optimized in various disciplines. In the initial proactive phase, the efficiency of virtual CAE methods is high and quickly decreases the development time.
Application of simulation technologies (RADIOSS) and optimization technologies (OptiStruct) in an early phase of the virtual product development process can fulfill complex demands of shorter product cycles and increased product complexity.

The ultimate challenges today are to become “faster – better – lighter – safer – cheaper” in order to achieve the ability to:

- make decision in the early phase of design cycle
- reduce design and manufacturing cost
- reduce trial and error procedure in design
- reduce cost of materials
- increase engineering productivity

This paper will describe the usage of automatic structural optimization methods within an early design phase of the development process for modern combustion engines using OptiStruct. As an example the scooter engine structure, this is largely made of aluminum die cast. Optimization techniques for cast structure are followed [2].

**Process Methodology**

*System Details*

Figure 1 shows a schematic diagram of the scooter engine structure consisting of crank case assembly. The housing has mainly three parts viz. crank case left (CCL), crank case right (CCR) & transmission case bolted together with M6 bolts as shown in figure 2.
The housing holds the crank shaft, transmission box and pulleys belt system. Cast iron inserts are fitted at the crank shaft bores to avoid crank hard surface running over aluminum made crank cases. The assembly therefore experiences combustion; crank inertial, pulley & transmission loads.

Moreover, the engine structure has three mounting points of which one is attached to the rear suspension, other two with chassis via a front link. The transmission output is given to the rear tyre. This kind of arrangement makes the vehicle dynamics influencing engine to swing about the front pivot. It also is clear that the road load excitations are experienced by the engine structure. The brake shoe is fixed at CCL.

Therefore, given the complex loading experienced by the engine, it is essential to analyze to the system in detail. Multi Body Dynamic (MBD) simulations and other analytical tools are employed to examine the following system:

- Crank Train Inertial
- Belt Pulley System
- Transmission System
- Vehicle Dynamics
- Braking Loads

Combustion pressure values are taken from tests. Based on the results of the MBD simulation critical load cycles are determined. The internal loads from engine are found to be critical when engine produces maximum power, torque or speed. Similarly, vehicle loads are critical in braking, bump & rebounds events.

**RADIOSS Model**

Finite element method (FEM) is used to analyze the system. The crank cases, inserts and transmission case are discretized using tetrahedral second order elements as shown in figure 3. The material properties are used as defined in Table I. The bolts are kept as 1D beam elements with steel diameter 6mm section rigidly tied at both ends with corresponding crank case threaded region. Each insert is tied to respective crank case.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus, E (GPa)</th>
<th>Poisson's Ratio, ν</th>
<th>Density, ρ (tonne/mm³)</th>
<th>Type of Element</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>70</td>
<td>0.35</td>
<td>2.7e-9</td>
<td>3D</td>
<td>CCL, CCR, Transmission Case</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>120</td>
<td>0.30</td>
<td>7.2e-9</td>
<td>3D</td>
<td>Insert LH, Insert RH</td>
</tr>
<tr>
<td>Steel</td>
<td>210</td>
<td>0.30</td>
<td>7.8e-9</td>
<td>1D</td>
<td>Bolts</td>
</tr>
</tbody>
</table>
The system is subjected to a total of 11 number of critical load steps as previously determined and solved for quasi-static condition.

**OptiStruct Model**

The topology optimization runs on the previously built simulation RADIOSS model. In OptiStruct, the model is divided into two regions viz. “design space” and “non design space” [3]. The design space forms the optimization space where optimization iterations are run. Non design space remains intact as no analysis is run here. Here, bearing resting and mountings are non design space as highlighted in figure 4. Rest of the part forms design space.

The objective of the optimization is to reduce the volume. To facilitate it, the design space total volume is taken as optimization response. An optimization response is an entity which is an outcome of the simulation. Further, with the volume design response an objective function is defined, targeted to minimize the response. The design space has been imposed with a constraint of maximum stress value. The constraints act as limits within which the optimization iterations would be run. With every iteration, the topology progress towards its objective while satisfying the constraints.
Results & Discussions

The base design results for most critical loading condition are identified and corresponding stress & displacement plots are as shown in figure 5. Similarly, other results are studied and it is observed that a significant regions in the structure always has a relatively higher factor of safety w.r.t. von mises stress. It is concluded that these regions are potential areas to remove weight. Moreover, the regions with lower factor of safety are also targeted for improvement using the optimization technique.

Figure 5: Stress & Displacement Plots for most critical loading condition

The optimization results are shown in figure 6.

Figure 6: Element Density Plot
Figure 6 shows the element densities, of which value of 1 indicates that the material is necessary for taking the loads, material must be kept here and value of 0 implies that the material can be removed from these areas. The figure 7 represent the optimized geometries of all the components including regions with element densities more than 0.15, because it gives a reasonable good geometry output, which can survive all the loading conditions as discussed previously i.e. keeping the stress within limits.

OptiStruct does a number of iterations before reaching a final optimized geometry. It starts with 0th iteration with element density of the entire region assigned as one. Subsequently, it solves the analysis, and based on the objectives & constraints, removes material by altering the element densities wherever there is a scope. Further iterations are done, till the convergence is reached, achieving the objectives without violating constraints. The geometry at one such intermediate iterative stage is shown in figure 8. As the iterations progress, the volume of the design space decreases as per the objective to minimize it. The volume plot is shown in figure 9. It is seen that the OptiStruct achieves the objective in initial few iterations and further change & corresponding improvement is insignificant, however these iterations help in determining convergence of solution.
The final optimized topology fulfills the constraint of maximum stress limit within the design space. Figure 9a shows stress plot of the optimum topology under most critical loading condition. The displacement plot for the same is shown in figure 9b.
Benefits Summary

The study shows a considerable reduction in the weight of the engine structure. The advantage is about 22% over the base design value. However, this is achieved after careful consideration of the geometrical constraints such as oil lubrication path, transmission layout & packaging etc. The weight reduction also helps in better fuel consumption, better vehicle acceleration & improved vehicle maneuverability.

Challenges

Accurate determination of the loads acting on the structure is the most important factor in this type of analysis. The system undergoes a lot of dynamics being a direct link between engine, vehicle chassis and road, thus pose difficulties to examine it. Moreover, failure to ascertain any critical load or running condition will potentially result in an unreasonable or wrong outcome. Therefore, a lot of groundwork is required as far as simulating the engine structure of a scooter engine is concerned.
Future Plans

The domain for analysis is sought to make larger & more accurate by including thermal group and thermal loads acting on the engine structure. Also, a multi objective multi constraint optimization is planned, where not only stress but natural frequencies will be made as an objective function and deformation as constraints.

Conclusions

The study elaborates a plan to reduce the engine weight. It will help engine designer to make engine more compact, lighter and cheaper. This process eliminates the need for large number of prototypes required for testing and thus drastically reducing the project development time.

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REFERENCES