TOPOLOGY OPTIMIZATION OF THE BELL CRANK & BRAKE PEDAL

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Abstract. Topology Optimization has been an effective tool for weight reduction and performance design and has essential applications in automobile industry. The main objective of this paper is to design a lighter weight bell crank and brake pedal than the existing design which is generally used in the automobile parts. The newly optimized design of bell crank and brake pedal is compared with the existing design. The CAD model of the bell crank and brake pedal is modeled using SOLIDWORKS software and the analysis of the newly optimized model is carried out using the Altair INSPIRE 9.5. Using the above methodology, a lightweight bell crank and brake pedal model is designed and the FEA analysis is used for obtaining the maximum and minimum value of displacement, % of yield, tension/compression, shear stress and von mises stress on the optimized design. The results of the design reflect that the weight of the bell crank has been reduced to 140 grams which is about 24% less weight than the existing design and the optimized weight of the brake pedal is reduced from 363g to 211g.

Keywords: Altair Inspire, Bell crank, brake pedal, FEA and Topology Optimization

1. INTRODUCTION

Topology Optimization is a computational methodology for the optimization of the geometries of various components. It is a mathematical procedure that optimizes the component layout within a given space constraints for a given set of loading and boundary conditions with a aim of maximizing the performance of the component. It optimizes the shape of the component in such a way that its weight is reduced and it performs in much similar way to the existing design without negotiating with the strength. Finite element analysis is used for analysis to implement the generated topologies [1]. Topology optimization has started given much importance since the last decade and hence consumers are looking for best of the products. Hence topology optimization plays a crucial role in the automotive industry. TO of various component is to make the less time to produce the product that is stronger, lighter and with less cost. The design and weight of that component has an essential influence on the performance of the cars. In order to reduce the cost of the manufacturing component the TO of the particular component has to take care of the manufacturing constraints. By reducing the weight of the vehicle using TO we reduce the fuel consumption and hence enhance the performance. When the mass of the vehicle is reduced the inertial forces required to be overcome by the engine is reduced and hence the energy required for moving the vehicle is reduced. Generally, the fuel consumption reduced by 5% by reducing the weight of the vehicle by 7-10% [2]. By reducing the weight of the single component may not give significant impact on the performance and fuel consumption efficiency of the vehicle, hence there is a requirement of optimization of various components as good as possible. Cavazzuti used the
method of TO to design the high-performance automotive chassis [3]. J. Bauer used the topology optimization method on structural trusses by taking discrete design variable [4]. Dongkaixu, Junchen and Yuchengtang, Jiancao have designed the stamping dies for automotive vehicles by using topology optimization so as to reduce the die weight and also its cost in order to improve fuel efficiency and vehicle safety. [5]. Kaya N. re-designed the failed clutch fork using topology and shape optimization by the response surface method [6]. Swapnil Thigale reduced the weight of Brake Disc using Topology Optimization. [7]. Lindan Yi used ANSYS software, takes topology optimization design of automobile engine bracket, and makes the strength analysis, fatigue analysis and model analysis of the new optimized bracket. The new bracket is having less stress concentration and its fatigue analysis are not based on real road load spectrum. [8]. Zheng used topology optimization in engine support structure of construction machinery [9]. The older TO formulation use the Finite Element Analysis to evaluate the design related performance of the component. TO has a wide range of applications in various sectors. This paper presents TO of the bell crank used in the suspension system of automobiles. Bell crank is a lever or rocker having two arms meeting at a pivot at a right angle, and is used for transmission of motion between two parts meeting at an angle. It is a type of crank that can change motion through an angle. The degree of angle can vary from 0 to 360 degrees but 90 and 180 degrees are most common. It converts the translation motion of one component into the translation motion of other component operating at different angles. However, the wider the angle extended by the crank, the more non-linear the direction of motion which builds up high stresses at the angles overtime [10]. A good example of bell crank is a bicycle brake where the force coming from the handlebar lever is rotated at an angle of 90 degrees to push the brake block against the wheel rim. It is being used in the suspension system in automobile, where it actuates the spring-damper unit with the help of either pushrod or pull rod. It is one of the most important components of the automotive suspension system. [10]. The results show that the newly optimized model of bell crank has similar performance characteristics as compared to the existing design without negotiating the required strength. The brake pedal finds its use in automotive applications for brake mechanism. The mechanism of braking system involves conversion of kinetic energy into brake energy commonly known as heat [11]. Mohd Nizam performed topology optimization of brake pedal with changing the material and found out that the new optimized brake pedal was 22% lighter as compared to the existing model [12]. K K Dhande, N I Jamadar and Sandeep Ghatge performed the topology optimization on brake pedal so as to reduce the weight as compared to the stock model without compromising on the performance efficiency of the brake pedal [13]. Currently used brake pedal contains excess material than the performance requirement leading to an increase in the weight of the vehicle. The brake pedals are largely made from metals but composite clutches and accelerator pedals have started using effectively in automotive sectors. This study is mainly concentrated on variable-material for the conceptual design, brake pedal profile, which is achieved by 78% lighter in weight as compared to the existing metallic pedals and 64% lighter weight as compared to the aluminum according to the General Motors specification. In Design, with the application of optimization, the aims of this paper is to reduce the weight of the existing brake pedal design of a car without the substitution of material. By reviewing the design constraints, load and boundary condition the optimization was run and the analysis was carried out using Altair Inspire. However, the result of the optimization process needs further refinement as it has a manufacturability deficiency. Thus, knowledge of design engineers to interpret and refine the proposed design is vital to ensure it is possible for production. In conclusion, the application of optimization with the integration of engineering knowledge of design engineer will be able to produce an optimal brake pedal design in a short time.

2. TOPOLOGY OPTIMIZATION OF THE BELL CRANK/TRAKE PEDAAL

Process flow for topology in Altair inspire
1) First step is developed the CAD model of the required part and generate a STEP format file.
2) Open Altair inspire and import the STEP file in it.
3) Now the software differentiates the model into 2 parts the design space and non-design space.
4) Design space is the selected region where topology optimization needs to occur, and the non-design space are the region which remain unchanged like mounting points, junctions etc.
5) The next step is to apply constraints for simulation, like support, force, pressure or moment etc. The material properties are also selected for the part.

6) Once all the above steps are completed icon for topology optimization is selected. Now there are 2 purposes minimize weight or maximize stiffness (for selected percentage of weight) as shown in the image below.

![Selection of stiffness](image)

Figure 1: Selection of stiffness

7) For the bell crank/brake pedal we have selected for maximum stiffness for given percentage of weight.

8) Once the simulation is done, we are presented with topology optimized rough surfaces.

9) Now in this software there is a feature called polynurbs which smoothens the surface to improve its mechanical property and it make manufacturable. After finishing this step, the part is completed and for 3D printing.

3. **RESULTS AND DISCUSSION**

We have done our FEA analysis on ALTAIR Inspire. The CAD model and the simulations are shown as follows:

**Analysis of bell crank**

![Stock model of bell crank](image)

**Figure 2.** Stock model of bell crank

![Optimized design of bell crank](image)

**Figure 2 a.** Optimized design of bell crank
Figure 3. Displacement analysis of bell crank
The displacement analysis (fig3) shows a maximum displacement of $6.75 \times 10^{-2}\text{mm}$ and minimum of $1.27 \times 10^{-3}\text{mm}$. These displacement values won’t have much effect on the components working thus proving a good stiffness of the design.

Figure 4. Yield analysis of bell crank
In the above figure we can see a maximum yield of 28.62% and minimum 0.06%.

Figure 5. Tension/Compression analysis of bell crank
In figure 5 the tension compression regions are highlighted this tells about the load pattern in bellcrank which also helps in failure analysis as well.a comparison with the stock model is also shown in the figure and values of tension and compression are also mentioned.

Figure 6. Shear stress analysis of bell crank
Max shear stress analysis is shown in the above figure the maximum shear stress observed was 5.94e^1MPa and minimum 1.303e^-1MPa

Figure 7. Von mises analysis of bell crank
(Min: 2.42e^-1MPa & Max:1.18e^2MPa)
From the above results we observe significant weight reduction up to 59%, factor of safety of 3.5, displacement all are within permissible limits.

Analysis of brake pedal:

In figure 9 the left figure shows stock model of brake pedal and right model is topology optimized, as we can see a truss pattern is stifferst iteration for this part within the given parameter of having a min factor of safety of 1.3.
Figure 9. Displacement analysis of the optimized brake pedal

Maximum and minimum displacement were observed to be 4.184e-004m and 0m respectively, these values are negligible and don’t affect the functioning of brake pedal.

Figure 10. Factor of safety of the brake pedal model

As discussed previously during topology optimization we enter a minimum factor of safety value and the optimization is based around two goals i.e either to achieve max stiffness or min weight, since the above pedal was simulated for max stiffness and a min factor of safety was entered 1.3 we received the above result.
Figure 11. Tension/Compression analysis

Figure 11 shows tension and compression distribution around the pedal which helps in failure analysis as well.

Figure 12. Von mises analysis of the brake pedal

As we can see their is significant difference between the two design of the brake pedal with help of topology optimization techniques the final weight has been reduced by 42%, the min factor of safety(see figure10) is 1.3(approx) and max displacement are within the safety range, the tension and compression simulation shows the load distribution at different regions of the pedal which important for failure analysis.
Our study compares the two different models for the bell crank lever under the same working load conditions using the Altair Inspire. The results drawn are compared for the deformation, over all von mises stress, compression/tension. It’s found that the second model is optimized keeping the stress and deformation in the safe limits. So if we apply same techniques for various components of a car such as uprights, brake caliper, seat mounts etc, we can achieve huge amount of weight and improve efficiency and performance.

4. CONCLUSION
The topology optimization was performed on the bell crank and brake pedal with two different goals, the bellcrank was simulated for minimum weight and brake pedal was simulated for max stiffness, this was visible in the final design of these components. The weight of the newly optimized bell crank is 140g less than that of the existing design and hence there is reduction in the weight of the component by 59%(approx). The weight of the newly optimized brake pedal reduced from 363g to 211 g. Also, with the help to TO there is an enhancement in the performance of the newly optimized design. In this way if perform topology optimization on various components of a car we can reduce the fuel consumption of the vehicle by weight reduction of the components without negotiating with the strength of the material, and also improve the vehicles dynamic performance.

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