Topology optimization of an ATV wheel hub

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Abstract: The article is based on the Topology Optimization of an ATV Wheel Hub. So, we use this methodology to reduce the unwanted material of the All-Terrain Vehicle (ATV) Wheel Hub and to reduce the weight. ATV is mainly designed for a competition, where the Hub is used to connect the wheel to chassis via steering knuckles and arm linkages. Hub plays a vital role in the ATV. So, designing of hub should be in proper dimensions. The hub material is designed with a help of SOLIDWORKS. And it was analysed by SolidWorks simulation. The material used for a hub is Aluminium alloy 6063-T6.

Keywords: Wheel Hub, Topological Optimization, Simulation, All terrain vehicle

1. Introduction
Nowadays Topology optimization plays a major role in the engineering world. It has wide range of application in Mechanical, Civil and Aerospace. Topology optimization is nothing but removing the unwanted material of the object and to reduce the weight of the object. Finite Element Method (FEM) is used to evaluate the design performance [1-5]. In olden days the result produced by the Topology optimization is quite difficult to manufacture. But nowadays results tuned for manufacturability. Here, we optimize the ATV wheel hub. The wheel hub has to be strong enough to withstand the force acting on it.

2. Nomenclature
F Force
T Torque
fmax force applied onto the master cylinder
Fmax force acting on each piston of the calliper
D diameter of the piston in the calliper
d diameter of the master cylinder piston
P hydrostatic pressure
Re effective radius of the disc
µ coefficient of friction

3. Wheel hub
A wheel hub is a very essential part of an upright assembly which serves as a solid connection between the rim and the upright. A wheel hub consists of 4 or more mounting points through which the wheel is attached using fasteners. It also serves as an attachment to the motor or the driveshaft. Hub also supports the vertical weight of the vehicle and in ATVs, it undergoes various shock load due to excessive vibrations during different conditions such as cornering, braking, bump etc.it are important that the chosen design of hub withstands these loads without failure during its life span. If the geometry and the material of the hub does not meet the required condition at each load it may fail anytime causing a total failure of the vehicle, also it is important to select an optimum lightweight
geometry so that the unsprung mass of the vehicle stays optimum since the increase in unsprung mass may reduce the handling of the ATV. The initial model or design space of the hub is designed using Solid works which is not detailed and contains only the necessary features such as the bore where the bearing is placed and the mounting points. making the design space or the initial model more detailed increases the time taken for the optimization. During optimization the shape is maintained within the volume of the initial design, the initial design or design space always has a higher factor of safety which indicates an inefficient use of the material. Optimization of this initial design is carried out to make the material usage optimal and increase the stress distribution. In the recent decades lightweight materials widely used in various industrial applications [4-16].

![Figure 1. 3D Modelling of initial wheel hub.](image_url)

### 4. Material properties

| Sr. No. | Property                  | 6063-T6                       |
|--------|---------------------------|-------------------------------|
| 1      | Ultimate Tensile Strength| 240000000 N/m²                |
| 2      | Yield Tensile Strength    | 215000000 N/m²                |
| 3      | Shear Modulus             | 2.58e+10 N/m²                 |
| 4      | Density                   | 2700 Kg/m³                    |
| 5      | Poisson’s Ratio           | 0.33                          |
| 6      | Elastic modulus           | 6.9e+10 N/m²                  |

The results for the Mass properties are shown in below images
5. Boundary conditions and weight

**Loads Calculations**: - The weight of the ATV is 320 kg. Considering average weight of person as 75 kg, total dead weight is 395 kg. Thus, net load on wheel hub can be calculated as many ways, here we will see the Braking torque and Bump force method.

**Braking Force**: Pedal force applied is assumed to be **200N**.

- Pedal ratio = 6:1
- \( f_{max} = \text{force} \times \text{pedal ratio} \)
- \( f_{max} = 200 \times 6 \)

\[ f_{max} = 1200 \text{ N} \]

\[ P = \frac{f_{max}}{\pi/4} \times 2D \quad \text{--------1} \]

\[ F_{max} = \frac{p \times \pi/4}{2d} \quad \text{--------2} \]

By solving 1&2 we get,

\[ F_{max} = f_{max}(D/d) \times 2 \]

\[ = 1200 \times (0.029/0.019) \times 2 \]

**Figure 2. Mass properties**

**Figure 3. Boundary conditions on wheel hub.**
\[ T = 3663.15 \text{ N} \]

**Torque acting on the disc:**
\[
T = F_{\text{max}} \times \mu \times R_e \times \text{number of pistons per calliper}
\]
\[
= 3663.5 \times 0.3 \times 0.080 \times 4
\]
\[
= 351.6 \text{ N-m}
\]

**Bump force:** Maximum velocity = 45 Kmph
Total weight = 320 Kg.
From Newton’s second law of motion,
\[ F = ma \]
Here we use 3g force,
\[
F = 320 \times 3 \times g
\]
\[
= 320 \times 3 \times 9.81
\]
\[ = 9417.6 \text{ N} \]
i.e. Force applied on each wheel is,
\[
(9417.6/4) + (351.6/0.25)
\]
\[ = 3761.1 \]

6. **Analysis and topology optimization**
To get pre optimized displacement analysis of wheel hub. It will be clearly mentioned in the below diagram.

- Maximum displacement = 3.892e-02
- Minimum displacement = 1.000e-30

![Figure 4. Displacement Analysis of initial wheel hub](image)

7. **Stiffness maximization of vehicle structure**
The objective of any optimization is to provide the best geometry model by considering the load conditions of the component given. The software must run results for the desired responses in this case of hub optimization, the objective was to optimize the weight of the hub without compromising the integrity and stiffness and the manufacturing goals such as PCD of the mounting holes and bore diameter of hub. The boundary condition given to the component was to minimize the mass by 40% while meeting the required geometric conditions to withstand the stress during a bump. Maximum and minimum stress level in any part can be of the component can be determined using the FEA method. The idea is to have a distributed stress over the component the variation in the stress acts as the major input of optimization. The indication of insufficient/overuse of material is determined by the stress variation between the elements. Based on this the rejection is done at the area where the
material is underutilized and is removed subsequently. The removal of material is done by deleting the element from the finite element model. In the mathematical model, von misses the stress of each element is compared to the von misses stress the whole structure. After each cycle the element which satisfies the condition, $(\sigma_{evm}/\sigma_{maxvm}) < R_{ri}$ is deleted from the model. The cycle repeats itself until the structure reaches a steady state. The optimization suggests a very coarse model of the component which is very difficult to manufacture thus the calculated smoothed version of the model is imported to a cadsoftware where it is redesigned to ease the manufacturability.

**Figure 5.** FOS of preoptimized hub

From the above images, we can see that the pre-optimized wheel hub as a FOS ranging from 1.5-2 which is quite optimal considering the practical results during the testing of vehicle. It also has a displacement ranging from 1.5-2mm at critical regions.

**Figure 6.** Optimization of wheel hub

From the above image, we get that the mass in the blue region does not affect the stiffness and also the FOS of the component. So, the hub is redesigned considering the above results.

Most of the mass in the blue region is removed in such a way that it does not affect the manufacturing standards of the component. Mass of the component is reduced from 365 kg to 233 kg. After Optimization of the wheel hub the following stages are.
A static study is again carried out on the optimized hub with same loading conditions as the preoptimized hub the results are shown above.
Figure 10. Top View of optimized wheel hub

Figure 11. Isometric View of optimized wheel hub

Topology Optimization suggest Optimized design of wheel hub as shown in fig. above which is very difficult to manufacturing or may have high cost to manufacturing. So, for efficient manufacturing process with low cost, component have to redesign according to manufacturability with sense of optimization.

8. Conclusion
An ATV hub of mass 365g is initially designed and the hub is simulated with a remote calculated load. The results of this study is taken to a Topology study where the mass is reduced by 40% then the hub is redesigned considering the topology study and is reduced to a mass of 233g and again a static study is run on the optimized hub where the results are satisfactory and the critical values lies between the optimal value.

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