Design and Analysis of Rear Wheel Hub and Steering Knuckle using Computer Aided Design (CAD) and Computer Aided Engineering (CAE).

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Abstract - The paper describes process of design and analysis for rear wheel hub & steering knuckle. In automotive system Wheel hub & steering knuckle system are attached to motor shaft (axle) and provide the support to the tie rods, and connect the trailing arm from chassis to the rear wheel, and fastening of brake caliper respectively. While designing the wheel hub & steering knuckle we have to work on overall shape, material specification, size, surface finish and appearance, and also ease of fastening & handling. As rear wheel hub & steering knuckle is undergoing radial load, axial load, tangential load, fatigue load during running condition in the various automotive system. The Design of Rear wheel hub and Steering Knuckle is done by using computer Aided Design software Creo 5.0, The Finite element analysis (FEA) is done by using Computer Aided Engineering software Ansys Workbench, FEA is used after designing process for checking the factor of safety and possible changes that can provide adequate safety design. And also for selecting the exact material by which we can make light weight wheel hub & steering knuckle with adequate properties so that it will survive against different load conditions with higher factor of safety.

Key Words: Wheel Hub, Steering Knuckle, Creo 5.0, Ansys Workbench, Safety, Light Weight.

1. INTRODUCTION

Wheel assemblies used in automobiles consist of Hub, Knuckle, Bearings and it is integrated as unibody or part components. Wheel hub and Steering Knuckle are important parts in automotive system, the main aim behind the study of design and analysis for rear wheel hub & steering knuckle is to evaluate the importance of wheel hub & steering knuckle in automotive system and how to make adequate design with required material. And in every automotive we have to count wheel hub & steering knuckle as a critical part because both help to connect chassis to wheel. So, we can’t imagine any automotive system without wheel hub & steering knuckle because while transmitting the motion from engine to wheel, the wheel hub & steering knuckle must be necessary. Wheel hub is located between brake caliper and knuckle. While knuckle is located between trailing arm i.e. rear suspension system only. Creo 5.0 is used for the 3-D modeling of hub and knuckle. After modeling we are going to test wheel hub & steering knuckle again with all the load conditions by performing stress-strain analysis using ANSYS 15.0 Workbench. The reason behind conducting stress-strain analysis is that the vehicle wheel hub & steering knuckle are undergoing various torque, thrust, and different load condition. So, we can make adequate changes in the material selection for manufacturing the same and also for design with higher factor of safety.

2. Methodology

Product Designing and Analysis is one of the most important and through process. At different design stages, and During the Analysis various problems occurred that need to be solved. This study has been followed in two parts. First part of this study includes modelling of Wheel Hub and steering knuckles component and In Second Part the analysis of both the parts under different loading condition is tested. CAD models of Wheel Hub and steering knuckle were developed in 3D modelling software, such as Creo 5.0. While the second part is of the models were then compared using finite element analysis (FEA) by ANSYS WORKBENCH 15.0

Approach of Study Shown in fig.1

![Fig-1: Approach of Study](image)

3. Material Selection

While we design any part of automotive system it involves so many things such across section determination, adequate strength, light weight, higher factor of safety. Among them material selection is very important because its effect on total cost, power transmission efficiency, density, material availability, total weight, manufacturing methods. The wheel hub is to be manufactured to take high axial, longitudinal and lateral loads from road surface, and during steering and turning the steering knuckle is subjected to compressive and tensile loads and due to the wheel rotation it is also subjected to...
torsional load. This above conditions can only be satisfied if the wheel hub and Steering Knuckle materials have high yield strength and ultimate tensile strength, Higher Factor of Safety, Young Modulus and Fatigue Strength.

The table below shows the material used for Wheel hub and Steering Knuckle,

<table>
<thead>
<tr>
<th>Table -1: Material for Wheel Hub</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Properties</td>
</tr>
<tr>
<td>Density (kg/m^3)</td>
</tr>
<tr>
<td>BHN</td>
</tr>
<tr>
<td>BRIN</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (MPa)</td>
</tr>
<tr>
<td>Tensile Yield Strength (MPa)</td>
</tr>
<tr>
<td>Young Modulus (Gpa)</td>
</tr>
<tr>
<td>Poisson Ratio</td>
</tr>
<tr>
<td>Fatigue Strength (MPa)</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table -2: Material for Steering Knuckle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Properties</td>
</tr>
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<td>Density (kg/m^3)</td>
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</tr>
<tr>
<td>Melting Point (°C)</td>
</tr>
</tbody>
</table>

4. Design and Finite Element Analysis

4.1 Rear Wheel Hub

The design of Wheel Hub is done with the help of Computer Aided Drawing (CAD) Wheel Hub is prepared in Creo Parametric 5.0, which is a computer graphics system for modeling various mechanical designs and for performing related design and manufacturing operations. The system uses a 3D solid modeling system as the core, and applies the feature-based, parametric modeling method. In short, Creo Parametric is a feature-based, solid modeling system with many extended design and manufacturing applications.

![Fig -2:3D CAD Model](image)

As shown in the figure below, the meshing was done with Tetrahedral free meshing, as the component had smooth curves, and cylindrical topology. The meshing was automatically refined at the points where there was discontinuity in the form of step, hole etc.

![Fig -3:Meshing of Wheel Hub](image)

The baseplate is bolted on to the wheel rim and hence constrained in 3 Degrees Of Freedom. Loads are applied on the other base plate.

Forces applied on Rear Wheel Hub are calculated as:

\[
\text{Braking force} = 2 \times \text{Pedal force} \times \text{Pedal ratio} \times \text{Ratio of bore areas} \times \text{Calliper pad and disc friction coefficient}
\]

\[
= 2 \times 600 \times 6.5 \times 0.35 \times 0.35 \times 2.23
\]

\[
\text{Braking Force} = 6087.9 \text{ N}
\]

\[
\text{Dynamic normal load on front axle} (F_{zF, dyn}) = (1 - v + \gamma a) \times g = (1 - 0.45 \times 0.388 \times 0.9) \times 310 \times 0.98
\]

\[
= 2734.557 \text{ N}
\]

\[
\text{Traction force} = 2734.557 \times 0.80 = 1093.82 \text{ N}
\]

\[
\text{Braking torque} = 1093.82 \times 11 \times 0.0254 = 305.61 \text{ Nm}
\]

\[
\text{Braking torque on front wheel} = 305.61 \times 1.5 = 450.42 \text{ Nm}
\]

Calculation of cornering force for Wheel hub

\[
\text{Vertical mass considered for calculation (m)} = 310 \text{ kg}
\]

\[
\text{Gross weight of vehicle } (G) = m \times g = 310 \times 9.81 = 3041.1 \text{ N}
\]

\[
\text{Longitudinal Force (F}_{\mu 1} = G \times = 2432.88 \text{ N}
\]

\[
\text{Lateral Force (F}_{\mu 2} = F_{\mu 1} \times \mu_1 = 310 \times 9.81 \times 0.80 \times 0.80
\]

\[
= 1946.30 \text{ N}
\]

We have the Equation,

\[
F_{\mu 1} \times rh + F_{\mu 2} \times rh + (G + F_{dec}) \times ras - Ns1 \times (ras + ras) = 0
\]

\[
(2432.88 + 1946.30) \times 0.432 - Ns1 \times 1.244 + (3041.1 + 2432.88) \times 0.622 = 0
\]

\[
Ns1 = 4222.95 \text{ N}
\]
Cornering force \((K_a) = (N_s1) \times 0.80 = 4222.95 \times 0.80 = 1689.18 \text{ N}\)

Factor of safety=1.48

Cornering force \((K_a) = 1689.18 \times 1.48 = 2500 \text{ N}\)

After applying load on the Rear Wheel hub the analysis is taken place with the help of ANSYS Workbench for finding Deformation, Stress generated and the factor of safety by using different materials as mentioned in table 1.

Following figure shows analysis for Rear Wheel hub by using Aluminium 6061 T6 -

**Fig -5**: Total Deformation on wheel hub

**Fig -6**: Directional Deformation on wheel hub

**Fig -7**: equivalent Von-Mises Stress on wheel hub

There are various forces acting on Steering Knuckle such as braking force, moment, lateral force, steering force as well as loads on knuckle hub in X, Y and Z direction.

Forces applied on Steering Knuckle are calculated as:

**Calculation of Stresses**

i. Stress Due to Axial Loads

The force of resistance per unit area, offered by a body against deformation is known as stress.
This is given by, \[
\text{Stress (}\sigma) = \frac{P}{A}
\]

ii. Stress due to Inertia bending force

Inertia bending load sets up a stress which would be tensile on one side of the knuckle and compressive on the other side and these stresses change sign in each half revolution. The bending moment (M) at any section ‘X’ from the small end is given by,

\[
M = \frac{x}{a} \left[1 - \left(\frac{x}{L}\right)^2\right]
\]

The Stress is calculated by \(\sigma = \frac{M}{Z}\)

\[
M = \frac{1}{2.5 \times x}
\]

\[I = 419 \times t^4\]

Loading Condition on Knuckle

For the calculation of load acting on steering knuckle component, the required loading condition which are as follows:

<table>
<thead>
<tr>
<th>Loading Condition on Steering Knuckle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Braking Force</strong> (1.5 \text{mm}) g</td>
</tr>
<tr>
<td><strong>Lateral Force</strong> (1.5 \text{mm}) g</td>
</tr>
<tr>
<td><strong>Steering Force</strong> 45-50N</td>
</tr>
<tr>
<td><strong>Force on the Knuckle hub in X-Direction</strong> (3 \text{mm}) g</td>
</tr>
<tr>
<td><strong>Force on the Knuckle hub in Y-Direction</strong> (3 \text{mm}) g</td>
</tr>
<tr>
<td><strong>Force on the Knuckle hub in Z-Direction</strong> (1 \text{mm}) g</td>
</tr>
</tbody>
</table>

Table 5. Loading Condition on Steering Knuckle

If the knuckle is designed for the vehicle of 1240kg weight, the braking force acting on it produced a moment, which calculated as:

\[\text{Braking force} = 1.5mg = 1.5 \times 310 \times 9.81\]

\[= 4561.65 \text{ N}\]

For calculation of braking force acting on one wheel is 1240/4=310kg, and considering perpendicular distance of 94mm:

\[
\text{Moment} = \text{Braking force} \times \text{perpendicular distance}
\]

\[= 4561.65 \times 94\]

\[= 428795.1 \text{ N-mm (for one wheel)}\]

Thus the resultant force is given by,

\[F = \sqrt{X^2 + Y^2 + Z^2}\]

\[X = 3 \text{mm} \times g = 3 \times 310 \times 9.81\]

\[= 9123.3 \text{ N}\]

\[Z = 1 \text{mm} \times g = 1 \times 310 \times 9.81\]

\[= 3441.1 \text{ N}\]

\[F = \sqrt{(9123.3)^2 + (9123.3)^2 + (3441.1)^2} = 13255.84 \text{ N}\]
Fig -16: Maximum Principal Elastic Strain on Steering Knuckle

Similar analysis is done for the other materials as mentioned in Table 2 for Grey Cast Iron and Aluminium 7075 T3.

5. Result and Discussion

5.1 Result for Rear Wheel Hub

From the Comparison Between the material which are used for the Static Analysis of Rear Wheel Hub We can conclude that Apart from the materials like Grey Cast Iron, Wrought Iron which are generally used for manufacturing the same can be replaced by the materials like Aluminium 6061 T3 and EN8 Mild Steel which are lighter in Weight and also having high strength. Reliability and other physical properties are also better than regular materials. By using materials like EN 8 Mild Steel, and Aluminium Weight of the wheel hub get reduced and also it will help to reduce the total weight of Assembly and overall Manufacturing cost and improve Power transmission Efficiency.

Aluminium 6061 T6 Possesses high strength, good corrosion resistance, weldability, and machinability. This alloy can be strengthened by heat treatment, which allows it to reach much higher levels of strength than non-heat treatable alloys. When 6061 aluminium is heat treated, they are great for general purpose uses and find many applications in structural materials, electronics and chemical equipments. Its versatility as a material comes from its characteristics and is regarded as a tough, resistant and easily-machined metal.

En 8 Mild Steel Possesses good corrosion resistance, high strength, weldability, and machinability, EN8 steels can be further surface-hardened by induction process, producing components with enhanced wear resistance. EN8 steel, in its heat treated form possesses good homogenous metallurgical structure, giving consistent machining properties.

Table 6: Comparison of material used for Static Analysis of Rear Wheel Hub.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Aluminium 6061 T6</th>
<th>EN 8 Mild Steel</th>
<th>Grey Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Deformation</td>
<td>0.003393mm</td>
<td>0.001386mm</td>
<td>0.005295mm</td>
</tr>
<tr>
<td>2</td>
<td>Directional Deformation</td>
<td>0.005920mm</td>
<td>0.0009094mm</td>
<td>0.0009243mm</td>
</tr>
<tr>
<td>3</td>
<td>Equivalent (Von-Mises) Stress</td>
<td>16.113Mpa</td>
<td>16.208Mpa</td>
<td>16.159Mpa</td>
</tr>
<tr>
<td>4</td>
<td>Maximum Principal Stress</td>
<td>17.731Mpa</td>
<td>16.803Mpa</td>
<td>17.349Mpa</td>
</tr>
<tr>
<td>5</td>
<td>Factor of Safety for Stress</td>
<td>4.82</td>
<td>4.96</td>
<td>4.52</td>
</tr>
<tr>
<td>6</td>
<td>Factor of Safety for Stress</td>
<td>2.3655</td>
<td>2.51</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Table 7: Comparison of material used for Analysis of Steering Knuckle.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>EN 47 Forged Steel</th>
<th>Grey Cast Iron</th>
<th>Aluminium 7075 T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Deformation</td>
<td>0.4396mm</td>
<td>1.1253mm</td>
<td>1.2069mm</td>
</tr>
<tr>
<td>2</td>
<td>Directional Deformation</td>
<td>0.2458mm</td>
<td>0.6107mm</td>
<td>0.7020mm</td>
</tr>
<tr>
<td>3</td>
<td>Equivalent (Von-Mises) Stress</td>
<td>388.117Mpa</td>
<td>794.133Mpa</td>
<td>781.333Mpa</td>
</tr>
<tr>
<td>4</td>
<td>Maximum Principal Stress</td>
<td>781.931Mpa</td>
<td>827.235Mpa</td>
<td>832.235Mpa</td>
</tr>
<tr>
<td>5</td>
<td>Maximum Principal Stress</td>
<td>0.003591</td>
<td>0.0099326</td>
<td>0.01101</td>
</tr>
</tbody>
</table>

Forge steel EN 47 is used, as it offers a better strength and lightweight for the steering knuckle component. Forge Steel materials are generally used where high tensile strength and toughness is required thus the Forge Steel EN 47 materials are suited for the steering knuckle component. Due to this low weight of materials, it can decrease the fuel consumption and it has low density and sufficient yield strength.

Aluminium 7075 T3 Possesses high strength, good corrosion resistance, weldability, and machinability, and this alloy can be strengthened via heat treating, which allows it to reach much higher levels of strength than non-heat treatable alloys.
6. CONCLUSIONS

We can conclude from this paper that when we are designing any part, material selection is very important, and by FINITE ELEMENT ANALYSIS (FEA) we can check its strength, rigidity and factor of safety for the product. FEA is very important when we design steering knuckle & wheel hub because both are very critical and crucial in the automobile system. And by using the 3-D modeling software we can know the weight of the designed part, and modify it fast, with time and cost savings. By using FEA we don’t have to perform multiple destructive tests for various load conditions and save analysis time. We can also know about the weak cross section regions, so that we can take precautions from failure. So using Creo 5.0 and ANSYS Workbench software it is very helpful to make adequate design with high strength, rigidity, light weight and higher factor of safety.

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