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Design and Analysis of Wheel Assembly

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Abstract: Wheel assembly is a very crucial system in a vehicle as its transfer forces come from the ground through the tire when the vehicle hits any bump or pothole on the road. Also the first part comes in contact when getting impacted from the side of the vehicle. There are lots of forces acting on it while braking, accelerating, cornering. And it's only part of the car that has physical contact with the road. Therefore any failure in Wheel assembly may lead to the breakdown of vehicles which could harm human life. As all components in wheel assembly are unsprung mass. To increase the performance, lowering the unsprung mass is beneficial. Therefore Design Wheel assembly that absorbs and withstand all forces which may lead to failure of the system, and which have minimum possible weight. In this report the complete design procedure of wheel assembly for R10 rims along with optimization and manufacturing processes of each part is presented.
Keywords: Upright, Knuckle, Hub, Wheel, Wheel assembly, Bearing, Optimization.

I. INTRODUCTION

Engine or Motor produces power and it is transferred through a power train or drive to the wheel and to the road which makes displacement of the car. And for turning of the vehicle driver provides torque to steering wheel Rack and pinion system convert rotational movement into radial movement and tie rod which connected to rack and pinion to one end and upright arm to other push tire in lateral direction the angle of arm decides ratio of steering.

Wheel assembly contains Wheel hub, knuckle, Bearings. And provides Physical mounting to the steering road (tie rod),

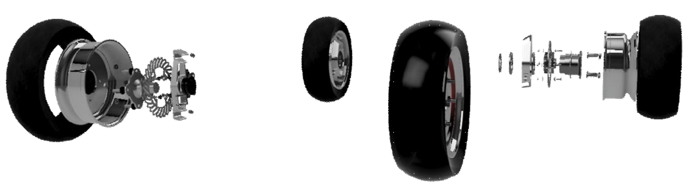

Fig.1 : Wheel Assembly

Suspension linkages, Brake caliper, Brake rotor and wheel. Rotating parts provide mounting to rotating components while stationary components were mounted on stationary parts. Knuckles have housing for bearing, where bearings are press fit in it. And the hub is press fit in bearing and free to rotate i.e bearings outer race is stationary and inner race is rotating with wheel hub.

There are two types of masses in vehicle sprung mass and unsprung mass. Sprung mass is the mass of a component or body which is supported by a spring damper system(suspension system), where unsprung mass is mass of part or body which is not supported by suspension system. Therefore Wheel assembly mass comes in the unsprung mass category as we know that unsprung mass not only affects the handling of the vehicle, but also reduces tire contact to track in bumping condition. Hence it is important to minimize the weight of wheel assembly. A good wheel assembly design sustains all forces acting on it, and does not fail in fatigue. And it follows DFM (Design for manufacture) and DFA (Design for assembly) which is also maximum optimized.

To achieve that goal we need to start from selecting the material. While selecting material take following criteria into consideration, which is Strength, Availability, Durability, Workability, Ease of Transportation, Cost. Then design the 3D model with modeling software (CATIA / SOLID WORKS / NX CAD / CREO /etc.) and the analysis the part in Structural Analysis software(ANSYS / HYPERMESH / SOLID WORKS /etc.)

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A. Design Constrains

1) R10 rim with PCD of 110mm. Rim dimension play very crucial role in design of Hub as PCD of hub is same as rim and knuckle is placed in rim which constrain the eye to eye distance of knuckle

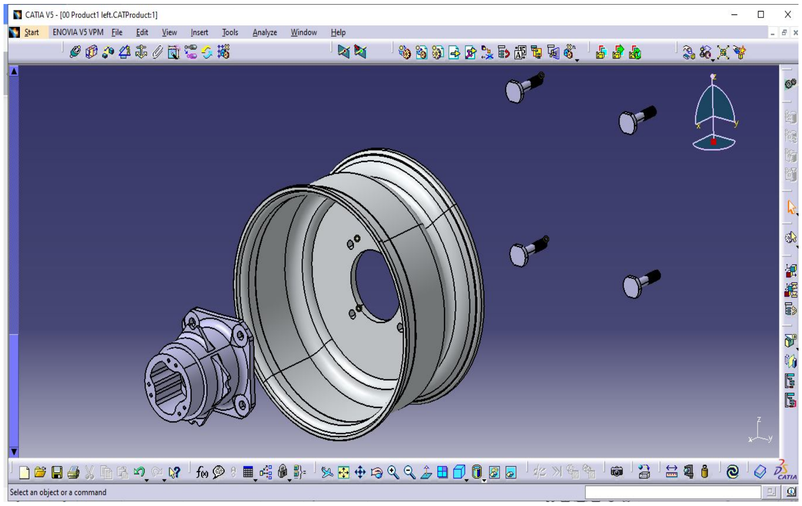

Fig.2 : Exploded view of Hub, Rim and Stud Bolts

2) In rim maximum knuckle of Eye to Eye distance 170mm. Can fit, Hence eye to eye distance of the knuckle is 170mm is selected as maximum the distance more the vehicle is stable in dynamic.

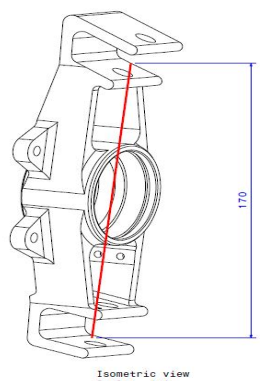

Fig.3 : Isolated view of Knuckle

3) Rim offside is 25.4mm(1 inch) this feature of rim affect the scrub radius of suspension geometry.

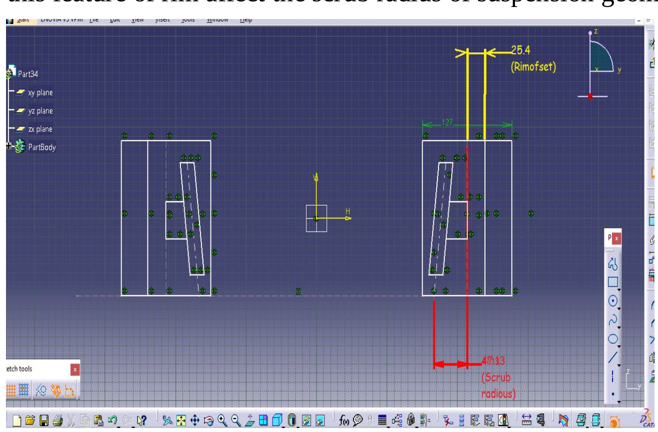

Fig.4 : Line diagram of effect of Rim offset on scrub radius

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B. Design Consideration

To design any system, it is necessary to take into account various parameters the system will be exposed to. Wheel assembly system is one of the two-which takes input from Steering system, suspension system, drivetrain and break system. The considerations made while designing the system are –

1) Coefficient of friction = 1
2) Weight of car= 250 kg
3) Minimum radius of track = 4.5 m
4) Weight distribution 45:55
5) Wheel base 1525mm
6) Height of the roll centre was decided to be 3 mm from the ground at front and 13 mm at rear. Generally, race cars prefer negative camber to have lateral force and toe out due to ease while turning.
7) The values of camber, caster and toe angles were decided to be -2, 4 and 0 degrees. These values would be attained when the vehicle is in a standstill position with a 70 kg person seated inside. The first decision to be made was the coordinates of mounting points and dimensions of the A-arms.
8) The King Pin inclination of 4 degree and vertical distance between mounting points of lower and upper A-arms of 140mm along with a track width of 1000mm at front and 143 mm along with a track width of 1100 mm at rear was chosen.

C. Material Selection

1) Mechanical properties of Al 6061 and Al 7075

Properties Al 6082 Al 7075
Density (g/cc) 2.7 2.81
Young's modulus 68900 MPa 71700MPa
Poisson's ratio 0.33 0.33
Ultimate tensile strength 310MPa 276MPa
Yield strength 275MPa 145MPa

Selection of appropriate material considering the operating conditions, fatigue life, elasticity hardness etc. Decides the endurance limit of the component.

a) *Upright:* The Knuckle should sustain the forces which are subjected to lateral and longitudinal load transfer as well as during braking and accelerating.
b) *Hub:* The hub should sustain excessive deflections, particularly in bending and torsion, which is mainly experienced during braking and acceleration.
c) *Steering Arm:* Connects the tie rod to knuckle for steering the wheel.
d) *Locking Plate:* For positive locking of the bearing for

Following is a table consisting major components of the system, their materials, process used for its manufacturing and machine used for manufacturing:

Sr no.	Part name	Material selected	Machining Processes	Various machines used
1	Front hub	AL 7075	Lathe turning and VMC surface milling	Lathe machine and VMC
2	Rear hub	AL 6082	Lathe turning and VMC surface milling	Lathe machine and VMC
3	Knuckle	AL 6082	Wire cutting and VMC	Molybdenum wire cutting machine and VMC
4	Steering arm	AL 6082	Milling	M1tr milling machine
5	Locking plate	MS	Laser cut	Laser cutting machine

Table 1: Components and machining process used

D. Design Process

Flow chart 1: Design Process

E. DFMEA: Design Failure Mode and Effect Analysis

Component	Failure mode	Failure cause	Failure effect	Severity	Occurrence	Detection	RPN	Preventive measure
Hub	Petals failed in shear	Inaccurate calculation of forces	System failure	10	6	2	120	Research on forces and design.
Knuckle	Failure at suspension points	Inaccurate calculation of forces	System failure	10	4	3	120	Research on forces and design.
Wheels	Wobbling at high speeds	Insufficient toe base	Decreased stability at high speeds	6	8	6	288	Increased toe base.
Bearing	Failure in bearing	Inappropriate bearing selection	Increased losses	6	5	3	90	Following standard procedure
Caliper mounts	Breakage	Excessive brake torque	System failure	10	5	5	250	Increasing the FOS considered
Knuckle hub assembly	Separation of hub and knuckle (dynamic)	Inaccurate tolerances to hub	System failure	10	4	2	80	Using positive locks wherever necessary.

Table 2: DFMEA of Wheel assembly

F. Design of Knuckle

Calculations of Forces Acting on Knuckle.

Knuckle is that part of the wheel assembly which is press fitted on the spindle and the A-arms are also mounted on the Knuckle. Besides the knuckle also serves the function of providing mounting to the Brake Caliper. The Steering Arm which is used to connect the wheel assembly and the tie rod is also mounted on the knuckle.

1) Longitudinal Forces During Braking

$$\text{Load Tansfer(Kg)} = \text{Acceleration(G)}\left(\frac{\text{Vehicle Weight(Kg)} \times \text{CG height(mm)}}{\text{Wheel Base(mm)}}\right)$$

Lode Transfer = 1.2 g (250*135) / 1555 = 26 kg

Weight on front wheel assembly = load transfer(kg) + (weight of car * 0.45)

Weight on front wheel assembly = 26 + (250 * 0.45)

Weight on one wheel = 138.5/2 = 69.25 kg

Force on one wheel assembly = 69.25 * 1.2 * 9.81 = 815.2 N

2) Longitudinal Forces during Acceleration

$$\text{Load Tansfer(Kg)} = \text{Acceleration(G)}\left(\frac{\text{Vehicle Weight(Kg)} \times \text{CG height(mm)}}{\text{Wheel Base(mm)}}\right)$$

Load transfer = 17.3 kg

Weight on front wheel assembly = load transfer(kg) + weight of car * (0.55)

Weight on front wheel assembly = 17.3 + (250 * 0.55)

Weight on one wheel = 155/2 = 77.5 kg

Force on one wheel assembly = 77.5 * 0.8 * 9.81 = 608.22 N

3) Lateral Forces while Cornering

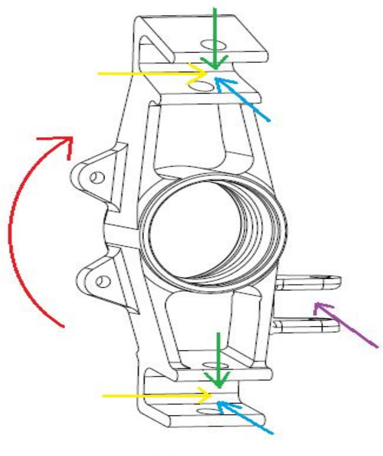

Fig.5 : Force distribution diagram

$$\text{Lateral load transfer} = \frac{\text{lateral acceleration(g)} \times \text{weight(kg)} \times \text{cg height(mm)}}{\text{track width(mm)}}$$

Lateral load transfer = (1.4 * 250 * 135) / 1000 = 47.25 kg
Fig.4 Forces Acting on Front Upright
Force on the outer wheel =1.4*9.81*((250*0.45)/2 + 47.25*0.45)
Force on outer wheel = 1064.5 N

4) Centrifugal Force
Let the vehicle take a turn of 6m turning radius and at a speed of 40kmph.
r = turning radius =6m
v = 40 kmph=11.11 m/s

$$\text{Centrifugal force} = \left(\frac{m \times v^2}{r}\right)$$

$$\text{Centrifugal force} = \left(\frac{(250 \times 0.45) \times 11.11^2}{6}\right) = 2314.35 \text{ N}$$

5) Force on the Steering Arm
According to the steering effort, the force on steering arm was found out to be at an angle of 15.7

6) Braking force
Braking torque on front wheel = 272.6 Nm
Braking torque on rear wheel = 176.4 Nm

G. Selection of Bearing

- At the front wheels, there are axial as well as radial forces which are acting on the bearing. This is due to the reason that the front wheel also has to steer the vehicle and also due to centrifugal forces while cornering. This is not the case in Rear Wheels. In rear wheels there are centrifugal forces acting, but the wheels are subjected to high speeds and torques.
- Taper roller bearing is incapable of sustaining such high speeds and torques. Deep groove ball bearing can sustain such high speeds and torques and hence at rear side deep groove ball bearing has been used. For this purpose, 2 deep groove ball bearings have been used.

1) Bearing Calculations

Axial Force = 1.5*9.81*100 = 1374 N

Radial force = 1656 N

$$\frac{Fa}{Fr} = 0.88 > 0.44$$

$\left(\frac{F_a}{C_0}\right)$	$\left(\frac{F_a}{F_r}\right) \leq e$		$\left(\frac{F_a}{F_r}\right) > e$		e
	X	Y	X	Y	
0.025	1	0	0.56	2.0	0.22
0.040	1	0	0.56	1.8	0.24
0.070	1	0	0.56	1.6	0.27
0.130	1	0	0.56	1.4	0.31
0.250	1	0	0.56	1.2	0.37
0.500	1	0	0.56	1.0	0.44

Table 3: X & Y factors for single-row deep groove ball bearings

X = 0.56; Y = 1.0

P = X*Fr*V + Y* Fa

V = 1 (Inner race rotating)

P = 0.56*1656*1+1471.5

P = 2398.86 N

Service factor is 1

$$C = P(L_{10})^{1/3}$$

L10 = 3.875 millions of revolution

$$C = 1411.32 \times (3.875)^{1/3}$$

C = 3767.866 N

According to the calculations done with reference to the manufacturer's catalog, it was found that the bearing **61805** is suitable for the front wheel assembly, as its value of C is less than 7.2 KN and Co is 4.3 KN.

For the rear wheel assembly bearing we selected NTN 6815 bearing considering Integrated tripod assembly in hub.

2) The Specifications of the 61805 bearing: The specification of the NTN 6815 bearing

Inner diameter of bearing =25 mm Inner diameter of bearing = 75 mm

Outer diameter of bearing = 42 mm Outer diameter of bearing = 95 mm

Thickness of bearing = 9 mm Width of bearing = 10mm

Basic Dynamic Load Rating = 7.2 KN Basic Dynamic Load Rating = 12.5 KN

Basic Static Load Rating = 4.3 KN Basic static load rating = 12.9 KN

Reference speed = 36000 r/min Reference speed = 7600 rpm

H. Design of Hub

It is used to connect wheel to a bearing load to the Upright. It endures weight of the vehicle and cornering forces and also used in power transmission.

- Both the Wheel as well as the disc is mounted on the hub with the help of bolts. As discussed earlier the outer race of the bearing is press fitted in the hub and hence provision is made in the hub to enclose the bearing.
- The Hub itself is made of 2 Petal parts. One of the wheels and the other of the brake disk. Torque on the Brake Disk Petal A torque of 272.5 Nm is acting on the Brake Disk Petal.

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1) Torque on the Wheel Petal

In order to sustain this braking effect, the wheel must also provide and equal and opposite torque. Thus, the magnitude of torque is same but the direction is opposite.

Force acting on each hole = (moment / radius) / 4
Force acting on each hole = (272.599 / 0.055) / 4
Force acting on each hole = 1239.08 N

2) Torque on the Brake Petal

A torque of 272.5 Nm is acting on the Brake Disk Petal.
Force acting on each hole = (moment / radius) / 4
Force acting on each hole = (272.599 / 0.0395) / 4
Force acting on each hole = 1725.310 N

3) Force due to Side Impact

If the vehicle is banged by other vehicle from side or if the vehicle has a collision with the fencing from side, there are chances that the petals might bend. Hence this side impact force must also be considered.

Here the side Impact force is taken to be 2g
Side impact force = (2 * g * vehicle mass)
Side impact force = (2 * 9.81 * 250) = 4905 N
Impact on one wheel petal = (4905/2) = 2452 N

4) Torque on Spindle

Mass on spindle = 69.25 kg
g= 9.81
Radius of wheel = 0.203 m
Coefficient of friction = 1
T = (m * g * r * coefficient of friction)
T = (69.25 * 9.81 *0.203 * 1)
T = 138 KN

I. CAD Model of Wheel Assembly

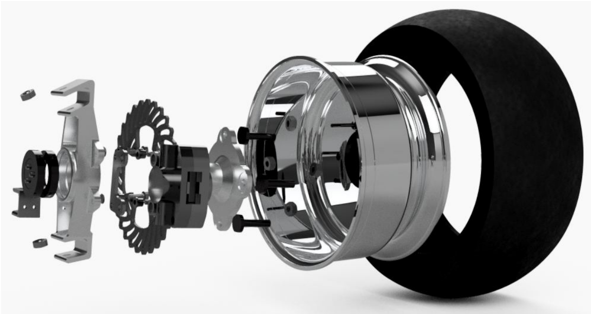

Fig.6: Front wheel assembly

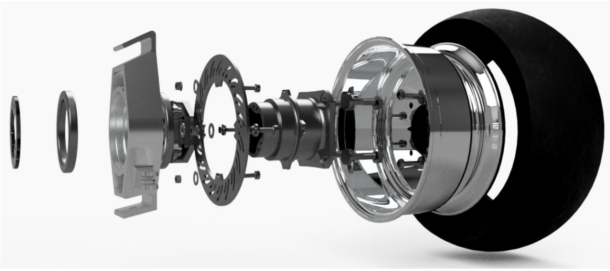

Fig.7: Rear wheel assembly

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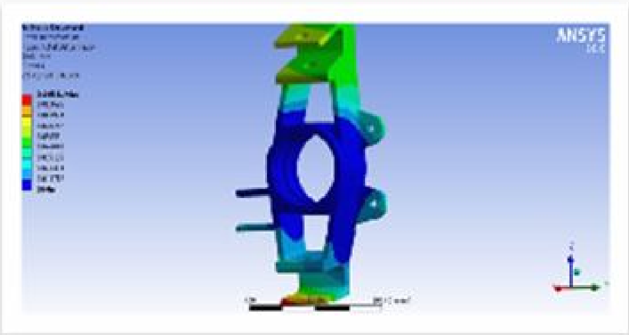
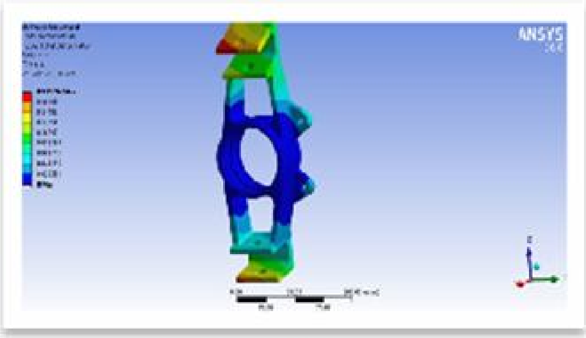
J. Front Upright Analysis

Before optimization

After optimization

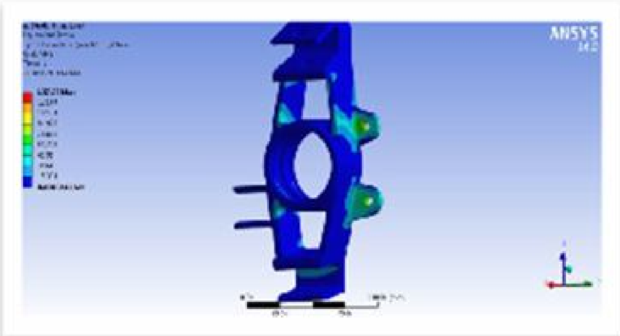


0.105mm Max

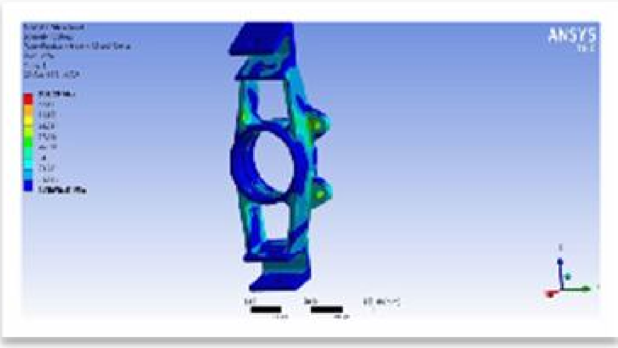


0.185mm Max

Fig.8 : Front upright deformation

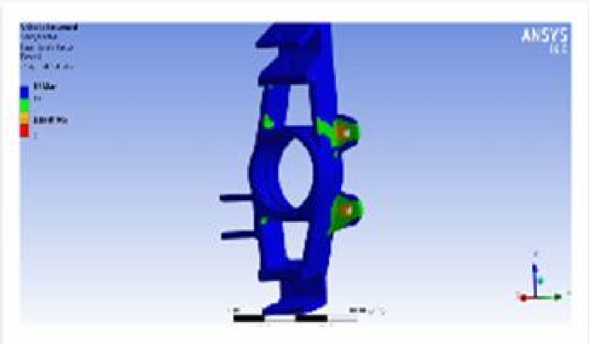


137.97 MPa Max.

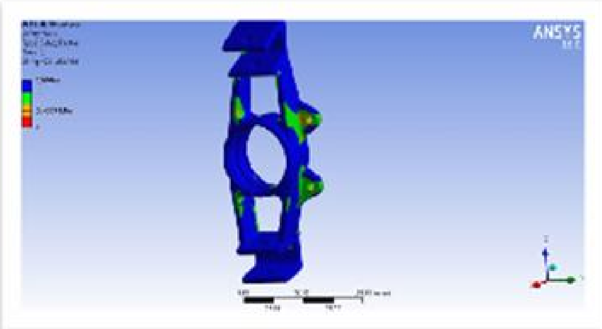


104.39 MPa Max.

Fig.9 : Front upright stress



FOS 1.88



FOS 2.49

Fig.10 : Front Upright FOS

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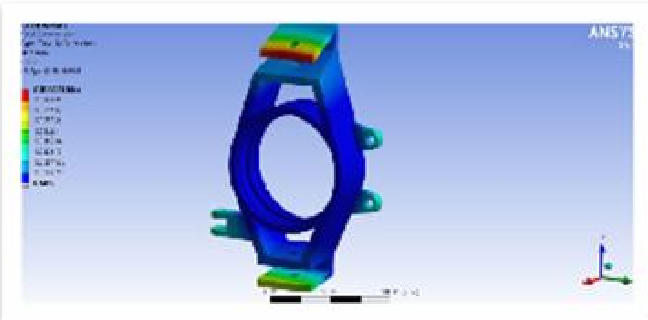
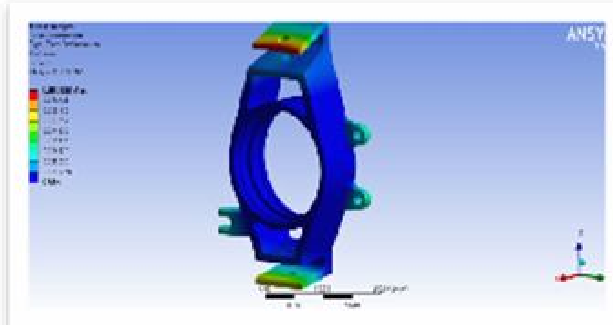
K. Rear Upright Analysis

Before Optimization

After Optimization

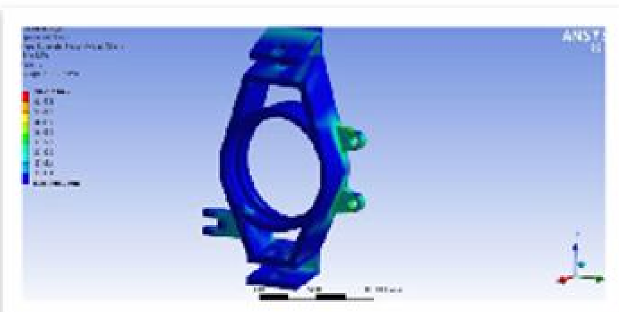


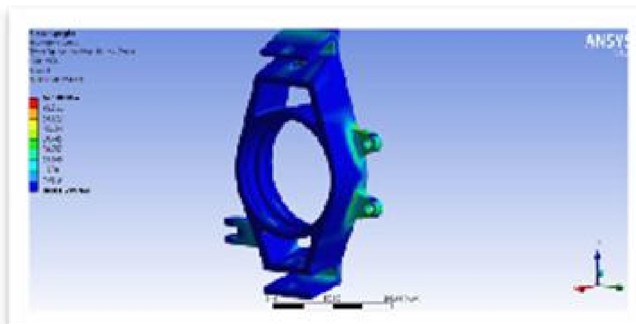


0.030mm Max

0.080mm Max

Fig.11 : Rear upright deformation

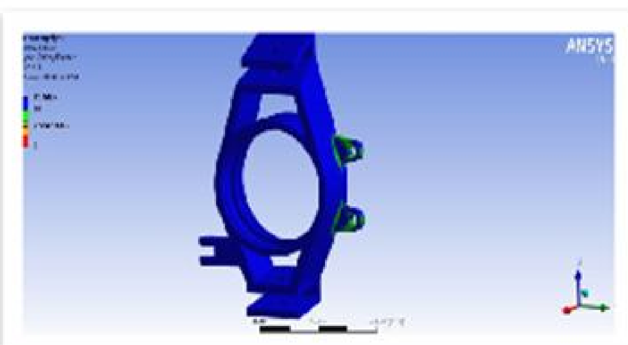


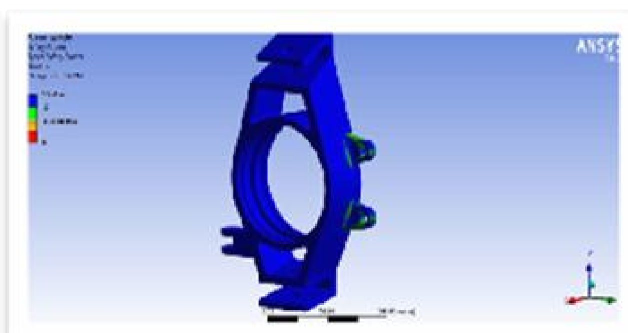


70.257 MPa Max

69.199 MPa Max

Fig.12 : Rear Upright FOS





FOS 3.9

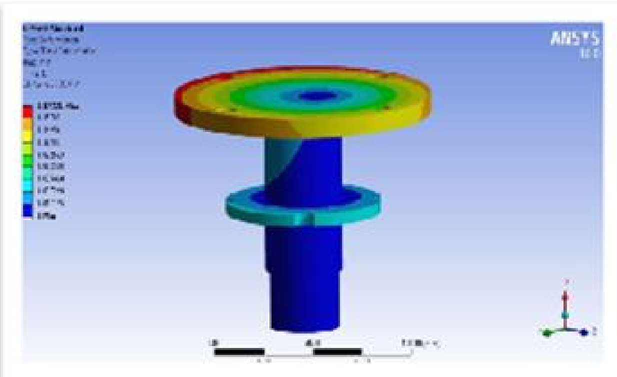
FOS 3.5

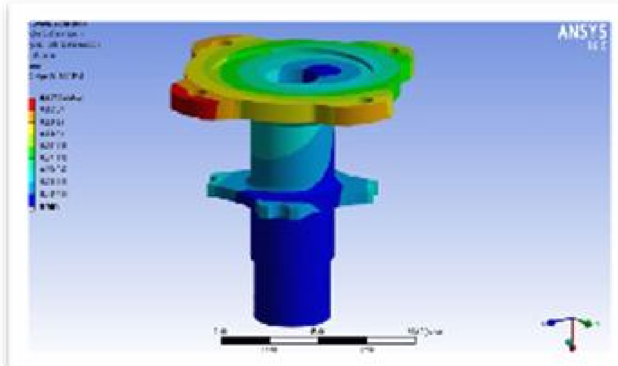
Fig.13 : Rear upright

L. Front hub Analysis

Before Optimization

After Optimization

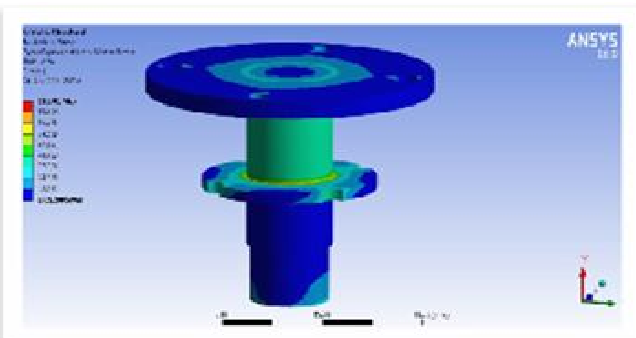


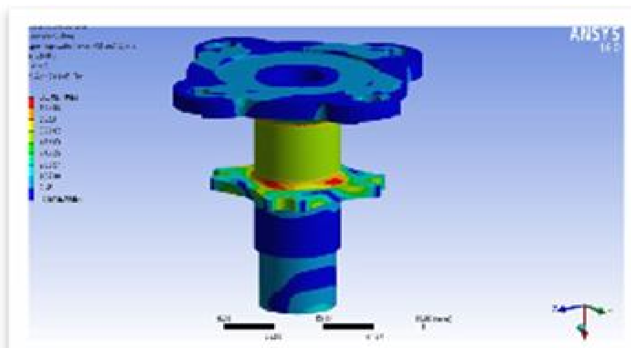


172mm Max

0.175mm Max

Fig.14 : Front hub deformation



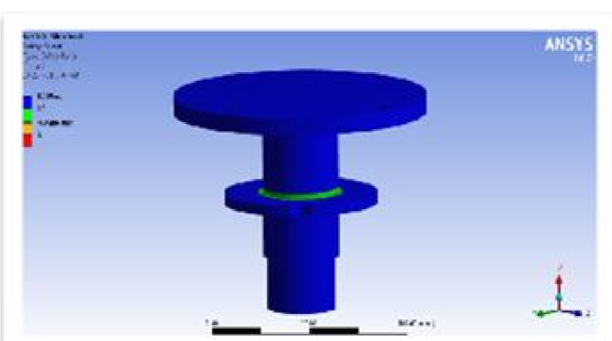


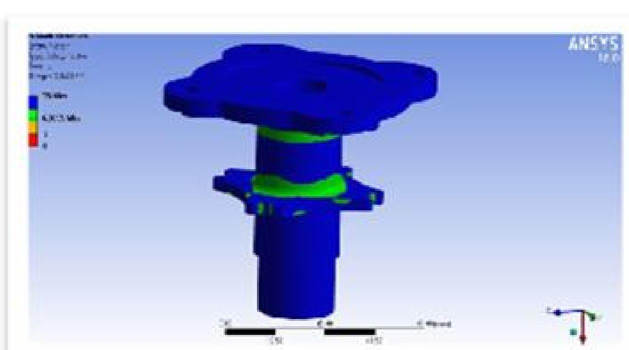
11.81 MPa Max

83.757 MPa Max

FOS 6.0

Fig.15 : Front hub equivalent stress





FOS 4.0

FOS 6.0

Fig.16 : Front hub FOS

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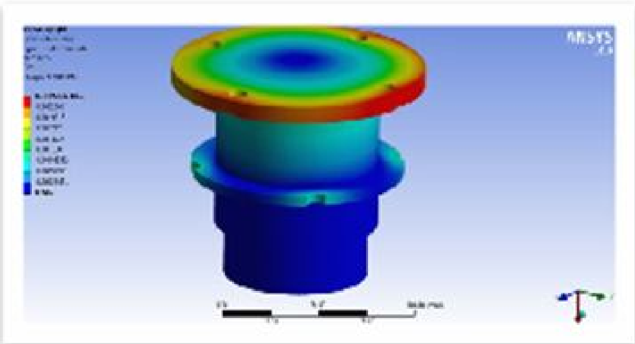
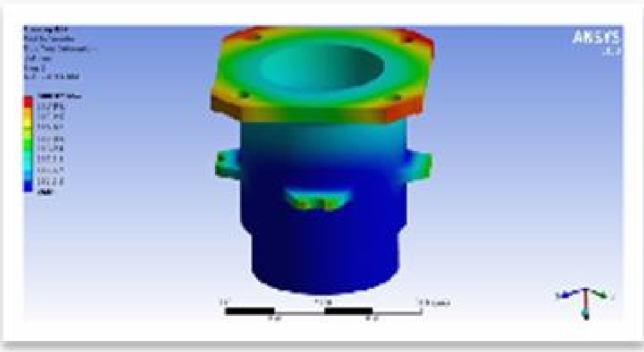
M. Rear Hub Analysis

Before Optimization



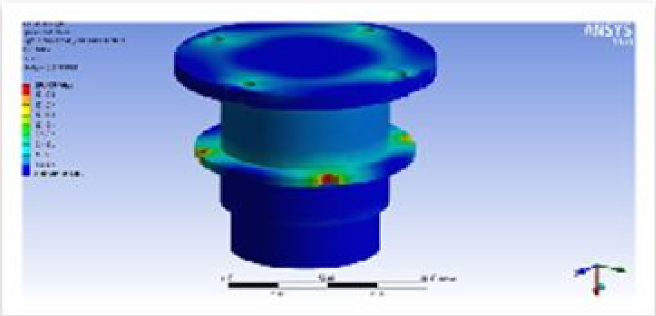
0.002mm Max

After Optimization

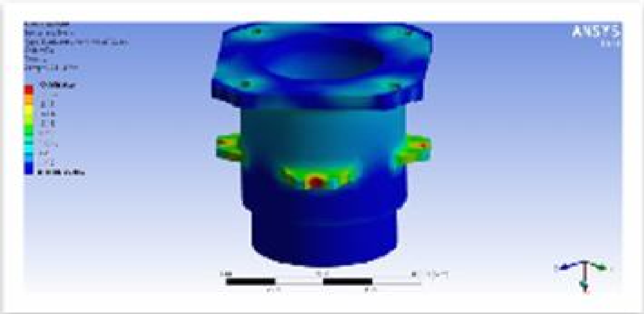


0.009mm Max

Fig.17 : Rear hub total deformation

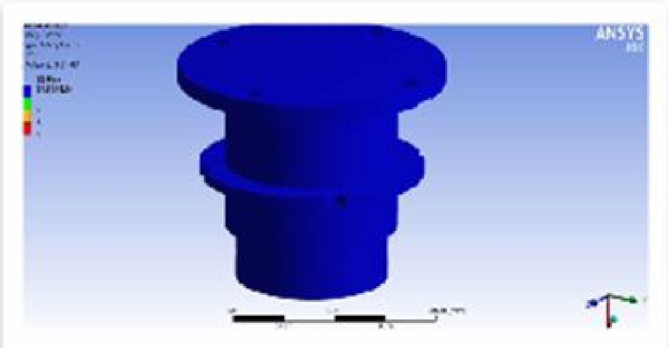


19.489 MPa Max

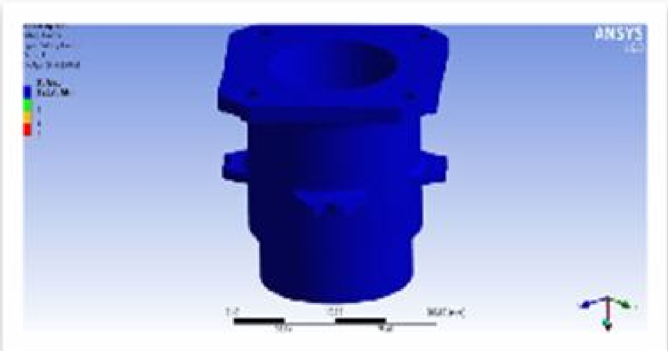


22.268 MPa Max

Fig.18 : Rear hub equivalent stress



FOS 12.828



FOS 12.125

Fig.19 : Rear hub FOS

N. Exploded view of Wheel Assembly Front and Rear

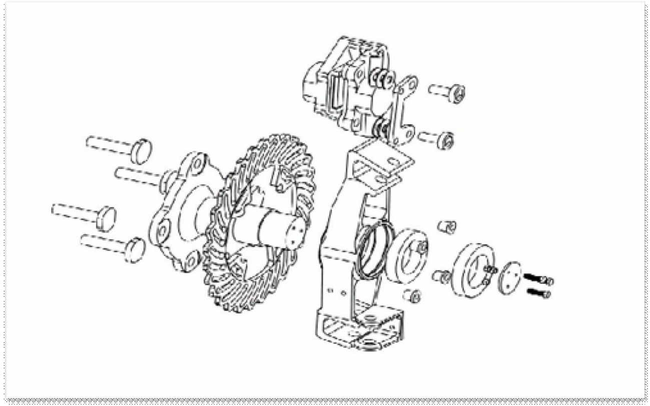


Fig.20 : Front wheel assembly

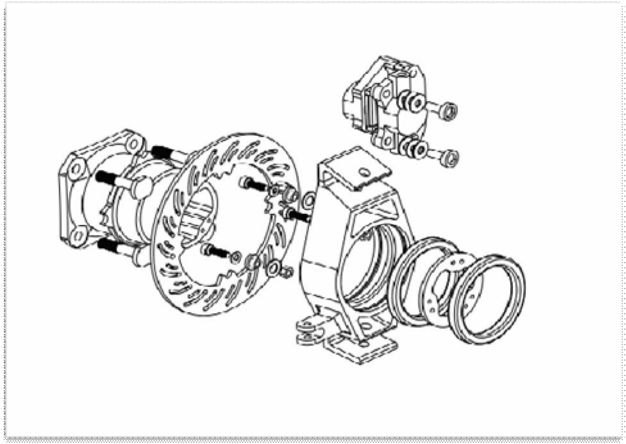


Fig.21 : Rear wheel assembly

O. Manufactured wheel assembly

Fig.22 : Manufactured front wheel assembly

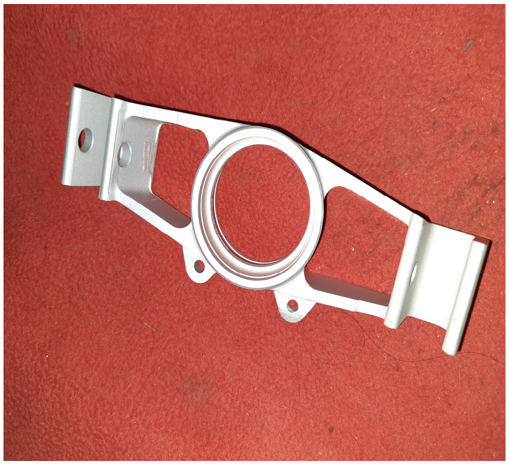


Fig.23 : Manufactured front knuckle

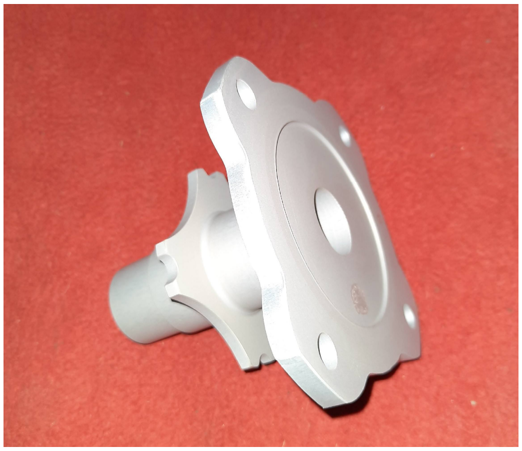


Fig.24 : Manufactured front hub

Fig.25 : Manufactured rear knuckle

P. System Summary

Table 4: System summary

Sr no.	Component details	Front	Rear
1	Upright weight	303gm	435gm
2	Hub weight	450gm	600gm
3	Bearing	NTN 6907	NTN 6815
4	Hub type	Floating disc mount	Integrated+floating disc mount
5	Hub material	AL 7075	AL 6082
6	Upright material	AL 6082	AL 6082

II. CONCLUSION

A. Reduction of weight was one of our primary aims. We found that weight can be reduced using structural optimization process.
B. To improve performance geometry has been modified using shape optimization which enables to reduce stress levels marginally below yield limit.
C. Lighter weight of upright and hub and required stiffness is achieved by optimum design calculations and less complex design.

III. ACKNOWLEDGEMENT

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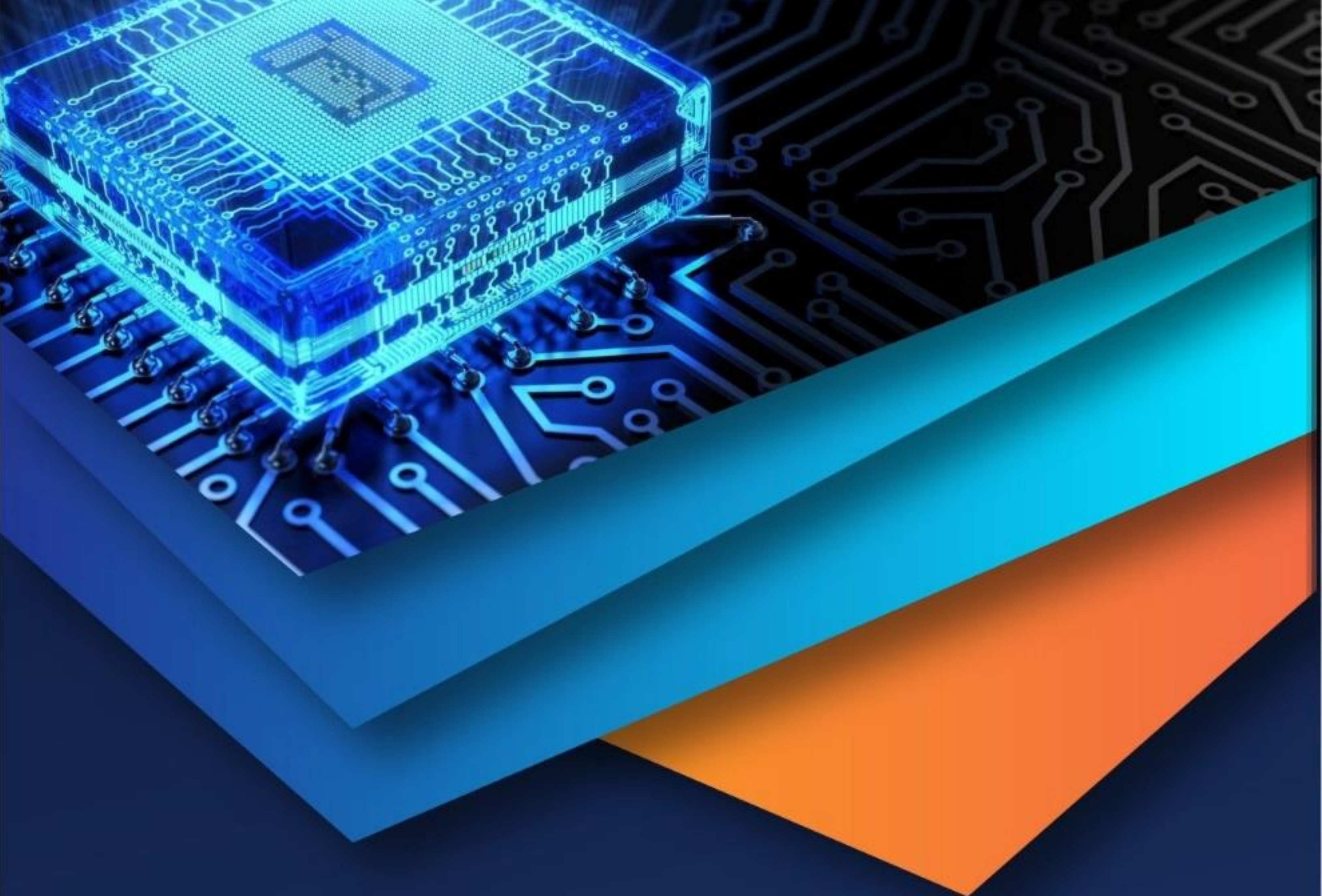

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