DESIGN AND ANALYSIS OF FRONT WHEEL ASSEMBLY OF A FORMULA STUDENT CAR

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Abstract - *Formula Society of Automotive Engineers (FSAE) is an organization which conduct the Formula Student competitions around the world where student from various engineering colleges participates with their self-designed vehicle. FSAE provides the platform for engineering students to apply their engineering knowledge to build a real-world Formula Student Car. The purpose for this project is to design wheel assembly for a formula student car while identifying & optimizing the critical component as Knuckle. The purpose of wheel assembly is to provide the physical mountings for the various components in vehicle including Wishbones, Steering Tie rod, Wheels, Brake Calipers etc. The wheel consists of Knuckle, Hub, Brake Disc, Bearing and Locking Components. The goals for designing the wheel assembly is to minimize the weight of wheel assembly as much as possible also to be cost effective while satisfying its purpose. The design of wheel assembly components is done using Solidworks software and structural analysis is done using Ansys software. The material study is done in brief to select the best possible material with better strength to weight ratio.*

Key Words: FSAE, Wheel Assembly, Knuckle, wishbones, Hub, Brake disc, Calipers, Solidworks, Ansys.

1.INTRODUCTION

The wheel assembly consists of following components:

Knuckle:

Knuckle is one of the important component of wheel assembly that holds suspension system and steering system components together It has mounting for wishbones, tie rods, bearing and brake caliper over it.

Bearing:

Bearing is the component in wheel assembly which is press fitted in knuckle and helps the hub to move freely while minimizing the friction.

Hub:

Hub is the component which connects wheel and the knuckle together and helps to rotate the wheel.

Brake Disc:

Brake disc is the component of braking system that helps to decelerate the vehicle. It is connected to the wheel hub which results in stopping the vehicle when brakes are applied.

Caliper:

Caliper is the component mounted on the knuckle and having brake pads in it generate friction on disc which results in stopping of vehicle.

Lock Nut, Locking Plate and Circlips:

The lock nut, locking plate and circlips are components which ensures the safety in dynamic conditions.

1.1 Material Selection

A steering knuckle needs to be designed in a such a way that it is capable to withstand the forces and moments acting on it due to bumps ,braking ,acceleration and steering of vehicle. To obtain the possibly best riding characteristics of a vehicle and to achieve it, unsprung mass of the vehicle should to be reduced. So, our goal is to design a wheel assembly which has lowest possible weight. During material selection the main aim is having high strength and less weight as compared to other commercially available knuckle materials. In this paper we propose Aluminum 7075 T6 compared to Aluminum 6061 T6, Mild steel A36 and Stainless Steel AISI 304.

Al 7075 T6

The composition of Aluminum 7075 T6 is 5.6–6.1% Zinc, 2.1–2.5% Magnesium, 1.2–1.6% Copper, and some other materials which are very less in composition like Silicon, Iron, Manganese, Titanium, Chromium etc. The specific strength of Al 7075 is very high. Al 7075 offers a better strength for the steering knuckle component. As in table given below we can see that yield and tensile strengths are higher than compared to other materials. It is one of the aluminum alloys with highest strength.

Young's Modulus (GPa)	71.7
Density (g/cc)	2.81
Shear Modulus (GPa)	26.9
Poisson's Ratio	0.33
Ultimate Tensile Strength	572
Yield Tensile Strength	503

Al 6061 T6

The composition of Aluminum 6061 T6 is Magnesium 0.80 - 1.20% ,Silicon 0.40 - 0.80%, Iron 0.0 - 0.70%, Copper 0.15 - 0.40% Chromium 0.04 - 0.35%, Zinc 0.0 - 0.25%, Titanium 0.0 - 0.15%, Manganese 0.0 - 0.15 %, etc. It offers better weldability but for knuckle we need material with good machinability. It is not as strong as Al 7075. It has no problem of corrosion as having less amount of copper.

Young's Modulus (GPa)	68.9
Density (g/cc)	2.7
Shear Modulus (GPa)	26
Poisson's Ratio	0.33
Ultimate Tensile Strength	310
Yield Tensile Strength	276

Mild steel A36

The composition of Mild Steel A36 is Carbon 0.25-0.29%, Copper 0.20%, Iron 97%, Manganese 1.03%, Phosphorous 0.04%, Silicon 0.2%, Sulfur 0.05%. It is one of the cheapest materials in the list. The material is easily available in market. It is very heavy .The strength to weight ratio is very bad as compared to Al 6061 T6 and Al 7075 T6 .

Young's Modulus (GPa)	200
Density (g/cc)	7.8
Shear Modulus (GPa)	79.3
Poisson's Ratio	0.26
Ultimate Tensile Strength	500
Yield Tensile Strength	250

Stainless Steel AISI 304

The composition of Stainless Steel AISI 304 is Iron 66.74-71.24%, Chromium 17.5-19.5%, Nickel 8-10.5% Manganese 2%, Silicon 1%, Nitrogen 0.11%, Carbon 0.07%, Phosphorus 0.05%, Sulphur 0.05%. The formability of AISI 304 is very good.

Young's Modulus (GPa)	195
Density (g/cc)	8
Shear Modulus (GPa)	86
Poisson's Ratio	0.29
Ultimate Tensile Strength	505
Yield Tensile Strength	215

All materials are mostly used where high tensile strength and toughness is required. So, Aluminum alloys are suited for the wheel assembly components. Due to this low weight of materials, it can decrease the fuel consumption and it have low density and sufficient yield strength. Al 7075 T6 being lighter and stronger than Al 6065 T6 makes it suitable to use for the manufacturing of Knuckle, Hub and Brake Disk.

1.2 Vehicle Specifications

The Formula Student vehicle is designed as per the standard Rulebook of Formula society of automotive Engineers. The wheel assembly is to be designed for the vehicle with following specifications.

Dimensions	Front	Rear
Trackwidth(t)	1150mm	1100mm
Wheelbase(L)	1550mm	
Total weight(w)	104kg	156kg
CG height(h)	229.59mm	
Turning radius	2.4m	

Static weight distribution is assumed to be 40 : 60 :: Front : Rear

1.3 Dynamic Force Calculations

As design and optimization of knuckle is directly related to the weight factor, if we reduce weight the efficiency of car automatically get better. So, our main focus is toward the optimization of knuckle so, for optimization we need different dynamic forces for analysis.

Consider speed during turning = 40 Km/hr

Weight distribution 40:60

$W = 260$ Kg, $W_1 = 52$ Kg,

$h = 228.59$ mm

$t = 1150$ mm

Lateral acceleration[6]:

$(Ay) = (tW-2tW_1) / -2Wh$

= 1.509 m/s2/9.81

= 0.15g

Lateral load transfer[6]:

$(LLT)_{front}$ = W× lateral acceleration × C.G height/ front trackwidth

= 260×0.15g×228.599/1150 = 7.752 kg

$(LLT)_{rear}$ = W × lateral acceleration × CG height/ rear track width[6]

= 260×0.15g×228.599/1100

= 8.103 kg

Longitudinal load transfer[6]:

LLT = W × longitudinal acceleration × CG height Wheelbase

= 260×0.5g×228.599/1550

= 19.169 kg

Vertical load acting on each wheel = 52*9.81=510.12N

Vertical force due to centrifugal couple[5]

= {(Total mass with driver) * (velocity) ^{2} * (Height of COG(H)}/{2*Cornering radius * Track width }

=1754.26 N

Vertical force due to gyroscopic effect[5]

= I ω ωp

= 4 * {Mass of each wheel * (Radius of tire(R)) 2/2}* {(Velocity of vehicle)2/ (Radius of tire *Cornering radius)}

= 1479.64 N

Net vertical load acting on wheel

= 510.12N+1754.26N+1479.64 N

= 3444.02 N

Centrifugal force (Lateral force)

= mv^2/R

= 3385.41 N

Bump force

= Wheel rate × travel due to bump

= 1277.79 N

Forces on steering arm

Static load on one wheel

= 52*9.81 N

= 510.12 N

Friction force

= 0.6 * 510.12 N

= 306.07 N

As Friction force rotates wheel assembly about steering axis.[5]

Torque acting about steering axis

= frictional force * scrub radius

= 306.07* 28.90

= 8845.42 N-mm

Force acting on tie rod

= Torque about Steering axis / length of Steering arm

= 8845.42/ 56.60 N

= 156.27N

Force on brake caliper:

Frictional force = Coefficient of friction * Total vertical load on one wheel[5]

= 0.6 * 1974 N = 1184.58 N

Braking torque on the wheel is the effect of frictional force acting in the contact patch of tire.

Braking torque (Tb) = Frictional force * Radius of tire(R)

= 1184.58 * 0.228 = 270.08 N-m

Force exerted on caliper mounting (Fc)

= Braking torque / Distance from center of spindle

= 270.08/55 =4910 N

1.4 Bearing Selection

At the front wheels the type of forces which acts are radial as well as axial forces. This is due to the reason the vehicle load acts on the wheel as well as axial thrust acts while cornering. Thus, it becomes important to use a bearing which can sustain radial as well as axial forces.

There are majorly two bearing which are usually used in front wheel assembly.

Ball Bearing :

It can sustain the radial Loads and there is point contact between balls and races.

Tapered Roller Bearing :

In tapered roller bearing there is a line contact and it is capable to withstand radial as well as axial forces. So, tapered roller bearing perform good under shock and impact loading, we are using tapered roller bearing.[1]

Data for Bearing Selection :
Radial Load = Fr = 1974.3 N

Axial Load = Fa = 3461.45 N

Equivalent Load = Fe = (X Fr + Y Fa) * Ks * Ko * Kp * Kr [2]

For Tapered roller bearing, C = 0.35

Fa/Fr = 3461.45/1974.3 = 1.75

As Fa/Fr > c

X=0.40, Y=2

Ks = Service factor

Ks = 1.3 for moderate shock

Ko =Kp =Kr=1

Fe = (0.40*1974.3+2*3461.45) *1.3*1*1*1

Fe= 10026.4N

Assuming,

Speed = 1200rpm

Bearing life =L= 5,000hr

L=5000*60*1200

L=360 million Revolutions

$L=(C/Fe)^{n} * Kret$

Where c = Dynamic load capacity

n=10/3 for tapered roller bearing

Kret = reliability factor

We are taking Kret = 1 for 90% reliability

$360=(C/10026.4)^{10/3}*1$

C=58.6kN

As per the above data we have to select the bearing which can sustain the above loads.

So, From SKF bearing catalogue we have selected 32305 2FD bearing which is having

Internal diameter = 25mm

Outer diameter = 62mm

Width = 25.25mm [3]

2. DESIGN METHODOLOGY OF COMPONENTS

2.1 Knuckle

In order to start the knuckle design, the tire and wheel size must be settled. As mentioned before, the car is aimed to be running on 10" wheels with 8" width and BKT GOLF CART TIRES 205/50-10 tires which are 18" in diameter.

The designing of knuckle starts from determining the position of upper and lower ball joint which can be determined by suspension hard points selection and the required parameters so as to improve the vehicle dynamics of the vehicle.

Following factors are used for knuckle design by studying the dynamic behavior of the vehicle.

Castor Angle:

In side view, Castor angle is the angle of the line joining the upper and lower ball joint. The value of castor angle affects the self-aligning torque of wheels. Therefore, 5 degrees of castor is used so as to get sufficient self-aligning torque.

King pin Inclination (KPI):

In front view, the king pin inclination is the angle of line joining the upper and lower ball joint. The king pin angle reduces the scrub radius of the tires and more value of king pin inclination leads to camber gain. Therefore 6 degrees of KPI is used as per suspension simulations and previous year data so as to get the required scrub radius and minimum camber gain.

The following figure describes the terminologies involved in upper and lower ball joint

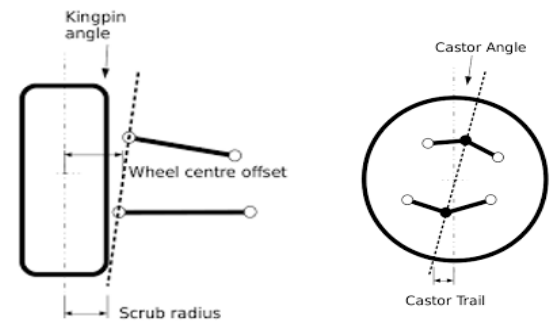


Fig-1: Terminologies in UBJ and LBJ

Ackerman steering:

Inclination of Steering Arm: The angle and length of steering arm defines the value of type of geometry of the steering and the wheel angle per unit travel of steering tie rod.

The inputs from Ackerman steering geometry is taken considering the speed characteristics of formula student vehicle, low speed geometry i.e., Ackerman steering geometry is used for designing the steering arm.

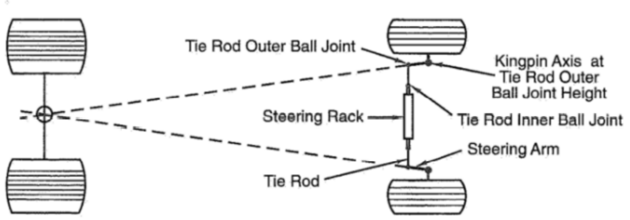


Fig.2- Ackerman, Parallel Ackerman, Reverse Ackerman Geometries

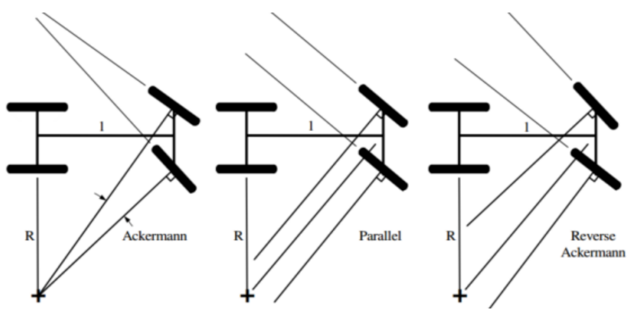


Fig-3: Ackerman geometry, with steering rack behind the axle line

Bearing and Caliper Mounting:

The Bearing mounting is designed as per the dimensions of Bearing to be used.

The Caliper mounting is designed as per the standard KBX OEM Caliper and considering the Brake Disc Diameter.

2.2 Analysis of Knuckle

The Knuckle is designed by the iterative analysis method and weight is reduced from the areas where the stress concentration is less and accordingly the design is optimized and finalized.

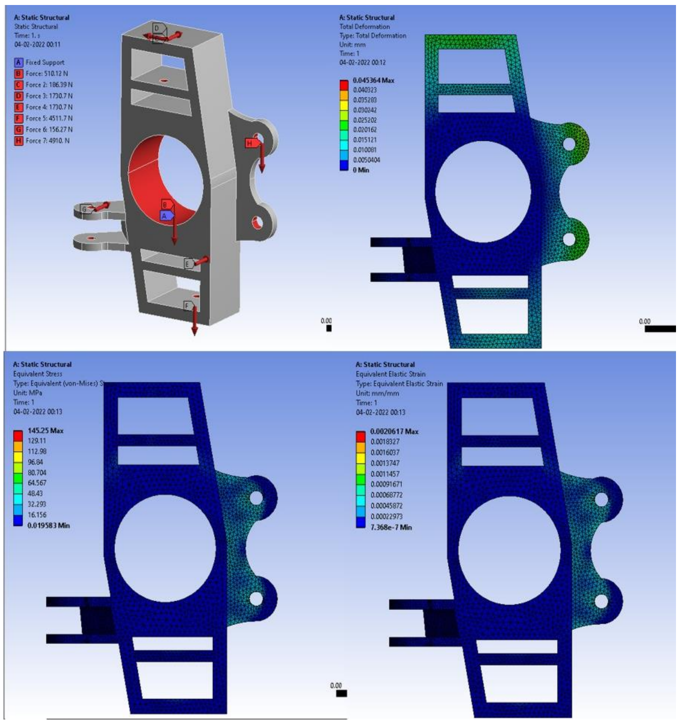


Fig-4 Analysis of Basic Knuckle

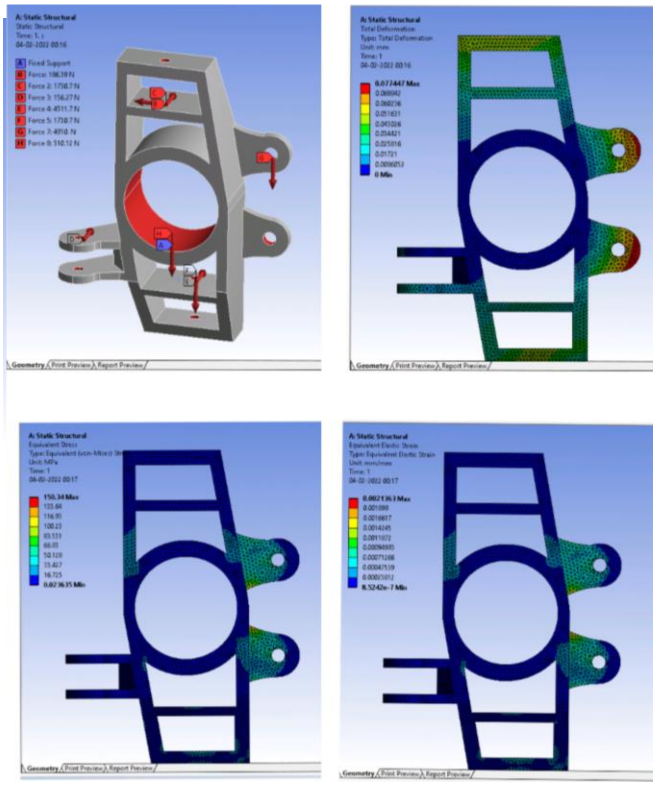


Fig-5: Analysis of First Iteration

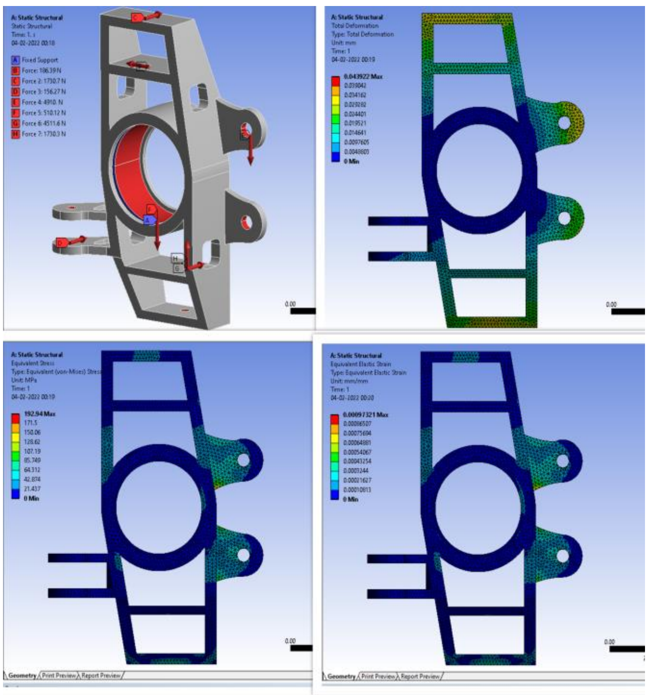


Fig -6: Analysis of second iteration

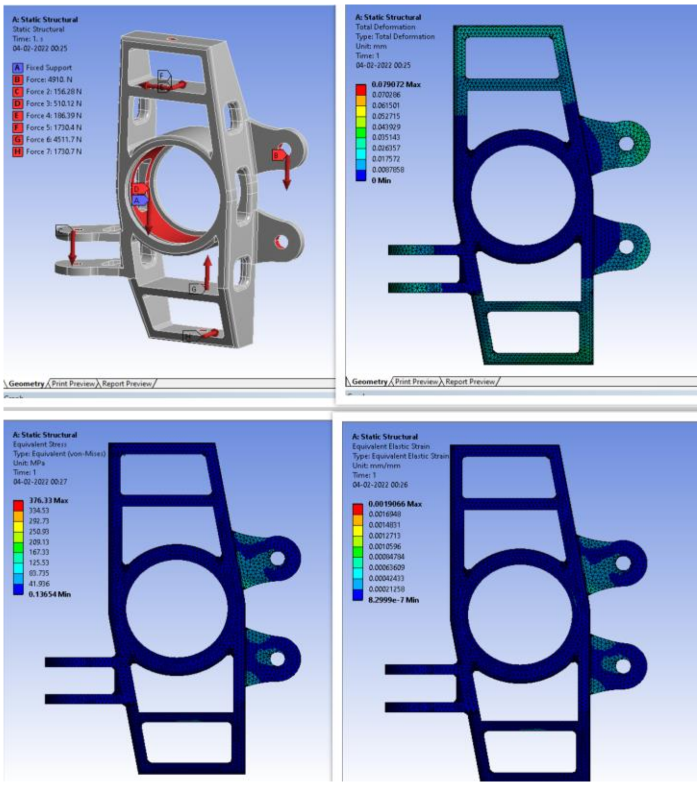


Fig-7: Analysis of final iteration

2.2 Hub

The Hub is designed by taking the constraints from wheel rim and brake disc and bearing and structural analysis is done to check the load bearing capacity of the hub.

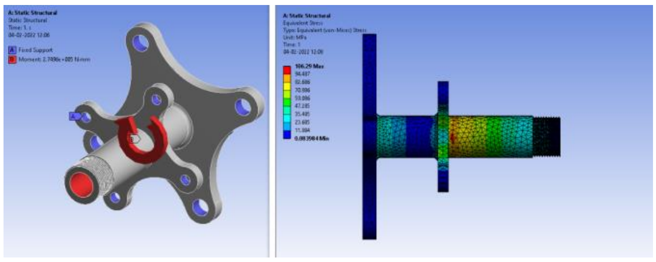


Fig-8: Analysis of Wheel Hub

2.3 Brake disc

The Brake Disc is the important component so as to stop the vehicle. The physical dimensions of the disc is decided as per the theoretical calculations and analysis is done so as to check the load bearing capacity of the knuckle.

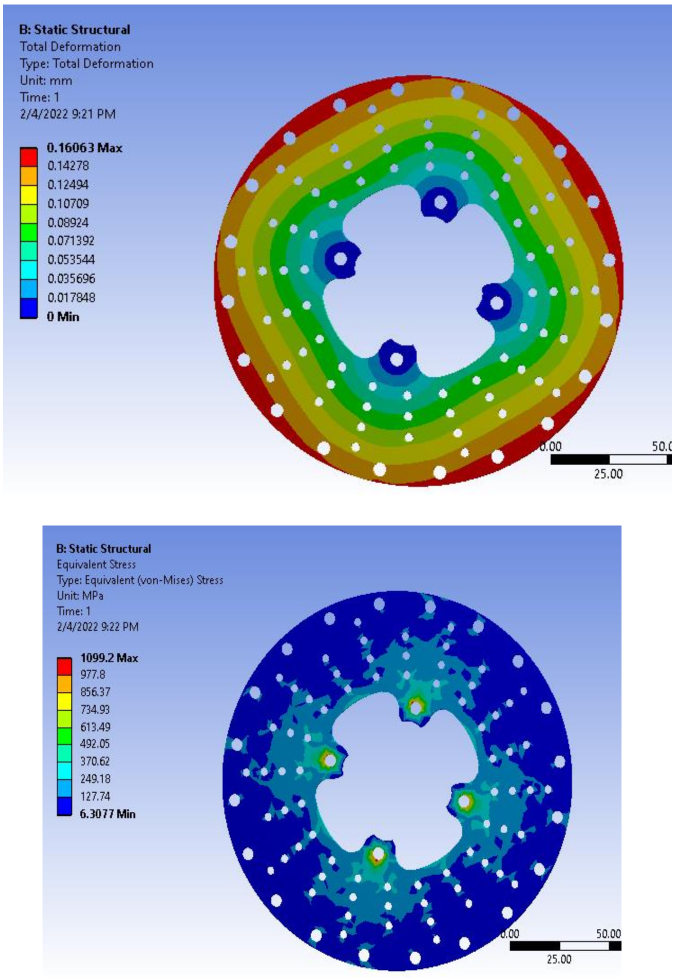
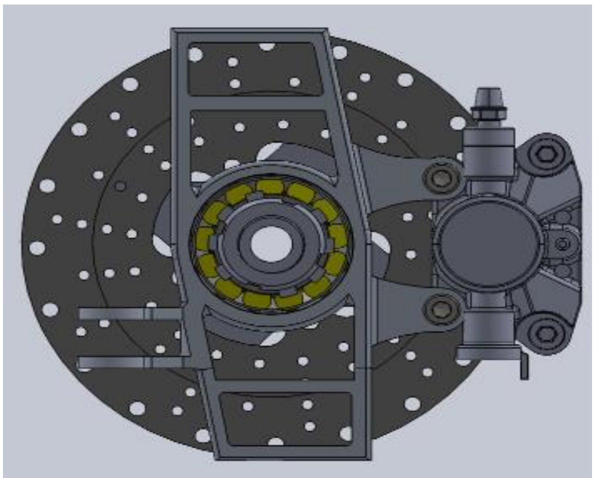


Fig-9: Analysis of Brake Disc

After designing and analyzing all the components the components are assembled together to get a useful product with rule compliance as per the FSAE community i.e., the knuckle is incorporated with positive locking mechanism by using locking plate and lock nut.



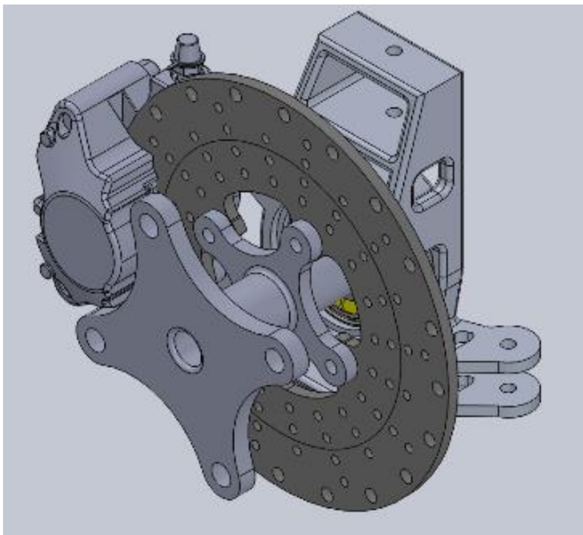


Fig-10: Final Wheel Assembly

3. CONCLUSION

The goal for this project is to design and analyze the formula student wheel assembly while the major focus was to optimize the knuckle. Other components are designed so as to sustain the dynamic and static forces acting on it. The design of knuckle is done while keeping in mind the previous years design and problems faced in it. We implemented the shape optimization technique to optimize the design of the knuckle which is to be used in the front wheel assembly of the car. The main objective of the shape optimization is to reduce the weight of the knuckle. As reduction in weight of the knuckle will tend reduce the weight of the overall wheel assembly. The results have shown that for the knuckle we have reduced almost 40 percent of weight

4. ACKNOWLEDGEMENT

We would sincerely like to thank our guide, Prof. M. A Hayat for his helpful guidance and assistance throughout the duration of this project. Many thanks also go to the Head of Department, Prof. Pramod Lanjewar for his continuous efforts for the Formula SAE team and his supervision over the event. Lastly, we would also like to thank our project review committee members Prof. M. S Khan and Prof. H. N Nagpure

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