DJS RACING STEERING

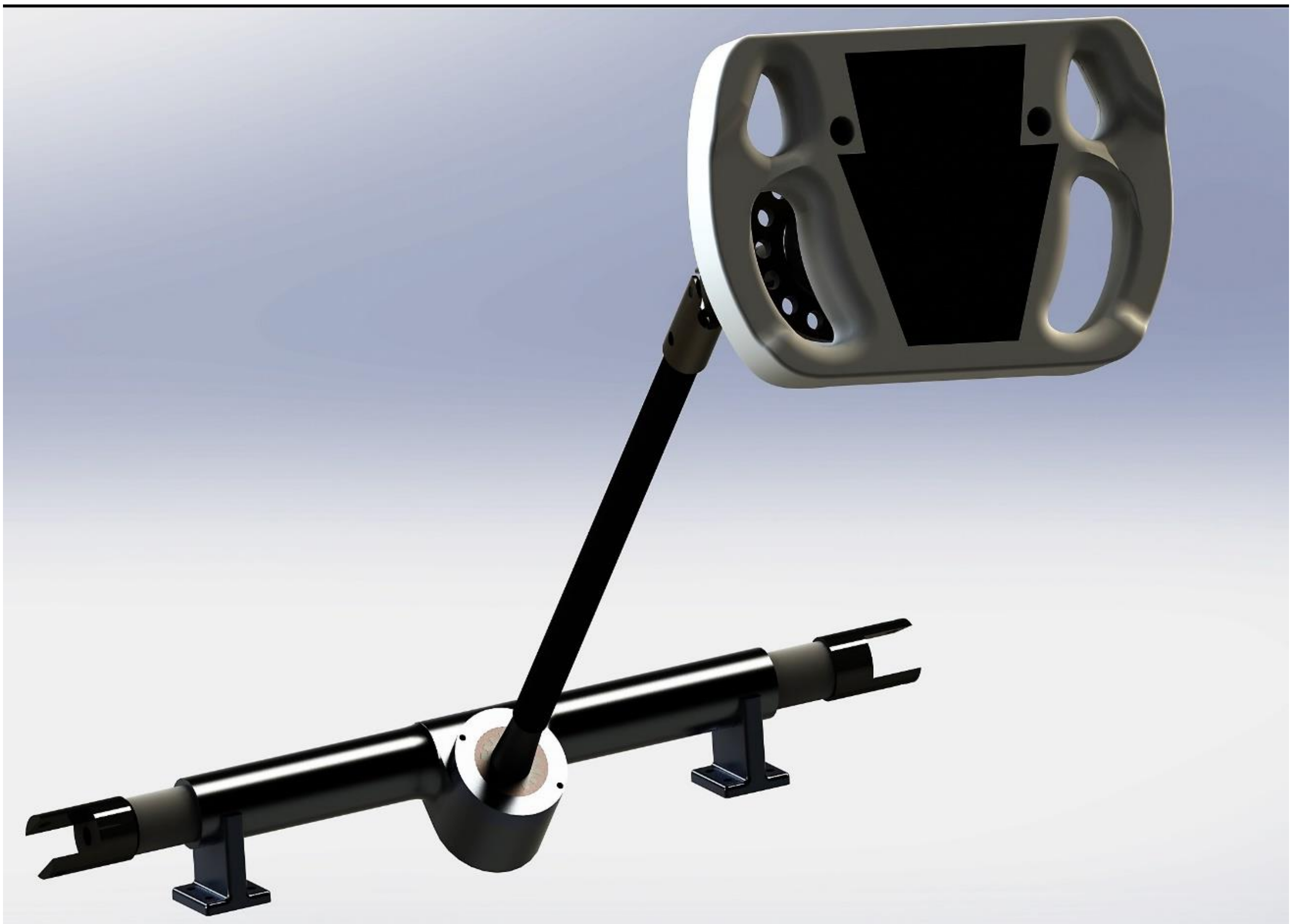


Table of Contents

1. Bill of Materials

Subsystem Name	Subsystem Component	Purchased/ Fabricated	Material	Quantity
Upper Assembly	Steering Mount	Fabricated	MS	1
	Hub	Fabricated	Al6061	1
	Steering Wheel	Fabricated	ABS,CF	1
	Quick Release	Purchased	-	1
	QR Shaft	Purchased	-	1
Column Assembly	Upper Column	Fabricated	MS	1
	UV Joint	Purchased	-	1
	Lower Column	Purchased	CF	1
	UV Insert	Fabricated	SS304	1
	Pinion Insert	Fabricated	EN24	1
Lower Assembly	Base Plate	Fabricated	MS	1
	Button	Fabricated	SS304	1
	Rack Teeth	Fabricated	EN24	1
	Rack Base	Fabricated	Al7075	1
	Pinion	Fabricated	EN24	1
	Clevis	Fabricated	SS304	2
	Housing Assembly	Fabricated	Al6061	1
Tie Rods	Tie Rods	Purchased	CF	2
	Tie Rod Inserts	Fabricated	Al6061	4
	Rod Ends	Purchased	MS	4

2. Design Goals

The main objectives of this year's design was to improve the cornering ability as compared to last year, reduce the weight of overall steering assembly and reduce the effort of the steering system. The entire system was designed and manufactured after performing ergonomics with the input of all the current drivers.

FLOW OF PROJECT-

1. Understanding problems faced by our previous car.
2. Meets regarding changes to be done for better performance.
3. Performing Ergonomics and its analysis.
4. Finalizing steering geometry with the help of solidworks and susprog3D.
5. Designing individual components with solidworks and its analysis using Ansys simulation.
6. Material procurement and Manufacturing.
7. Post processing of components for increasing strength.
8. Destructive testing of CF tubes.
9. Final Assembly on car and its testing.
10. Changes required after testing.

3. Steady State Calculations

Wt. of car = M = 245kg

Front track = 1200mm

Rear track = 1150mm

Wheelbase = 1550mm

Height of CG = 254mm

Weight distribution = Front: Rear = 50:50

Mass on front axle = 0.5*245 = 122.5Kg

Mass on rear axle = 0.5*240 = 122.5Kg

Mass on front wheel = 60Kg

Mass on rear wheel = 60Kg

Cornering g's = 1.2

Static camber front = 0°

Static camber rear = -2°

Caster angle = 7.5°

Kingpin inclination = 13.9

Static Ackerman = 100%

Front axle

Reaction Force = 40.64N

Outer Wheel(Wt.) = 100.64Kg

Inner Wheel(Wt.) = 19.36Kg

Rear axle

Reaction Force = 42.40696N

Outer Wheel(Wt.) = 102.407Kg

Inner Wheel(Wt.) = 17.5934Kg

Lateral Forces Obtained

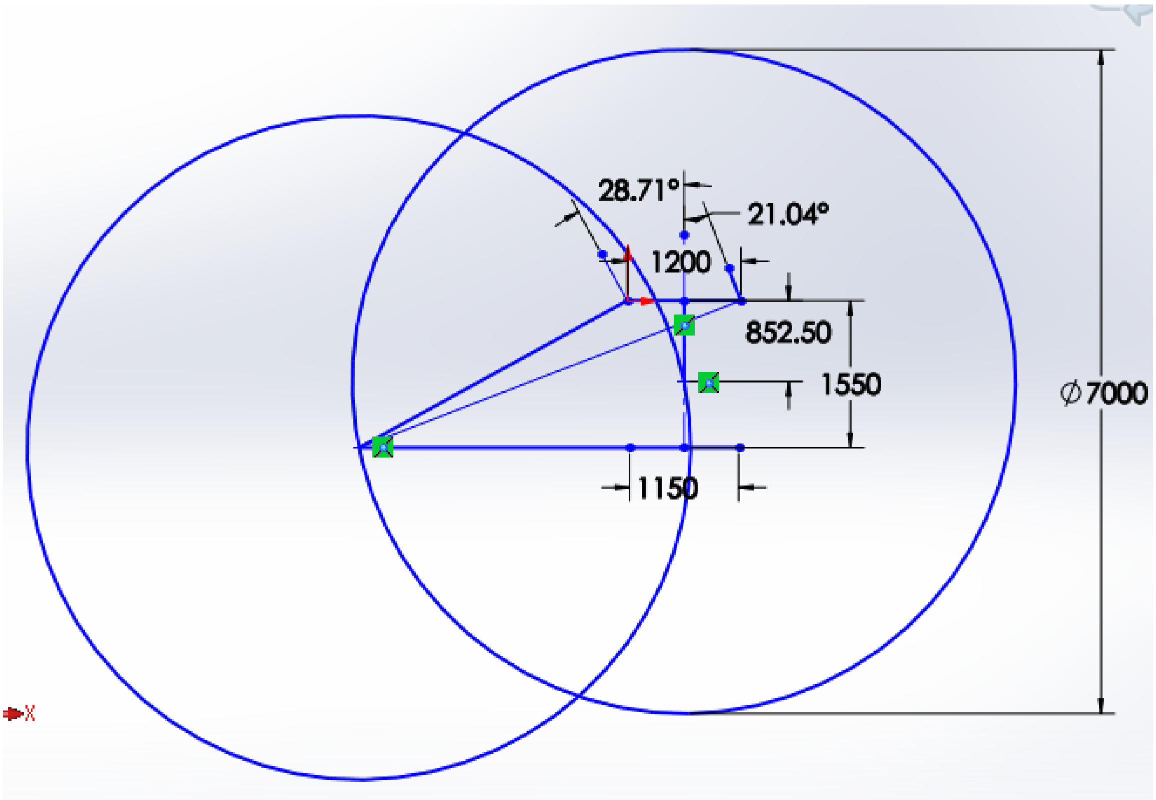
Front Outer = 1579.645N

Front Inner = 303.8746N

Rear Outer = 1607.38N

Rear Inner = 276.1404N

STEERING GEOMETRY:



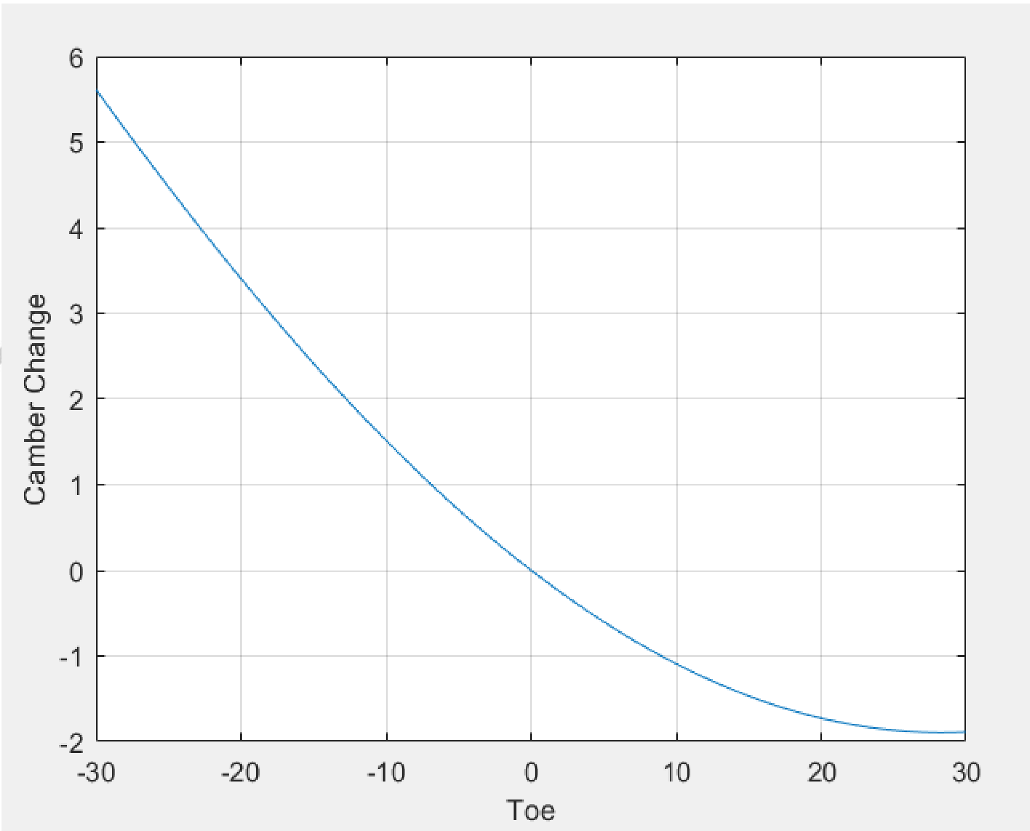
Steering angles were selected based on the radius of the turn and slip of the tire.

The basic geometric angles were derived from the sketch. The wheelbase and track of the car were defined in the sketch along with the turning radius of the corner. A turning radius of 3.5m was decided taking into account the smallest turn at the event. The car is assumed to be taking the turn at steady state.

The geometric angle of turn for the outer tire is 21.04˚ and 28.71˚ for the inner tire. Compensating for slip, the required steering angles are **27.03˚ outer and 35.754˚**

Change in Camber with Toe:

```
KPI=13.9*pi/180; %degrees%
Cas=7.5*pi/180; %degrees%
for i=1:61
alph (i) =(i-31)*pi/180;
CV(i)= KPI*(1-cos(alph(i)))-Cas*sin(alph(i));
end
plot(alph*180/pi,CV*180/pi);
xlabe('Toe');
ylabe('Camber Change');
grid on;
hold off;
```



Camber change on the outer wheel is up to 2˚ when it is turned by 30˚

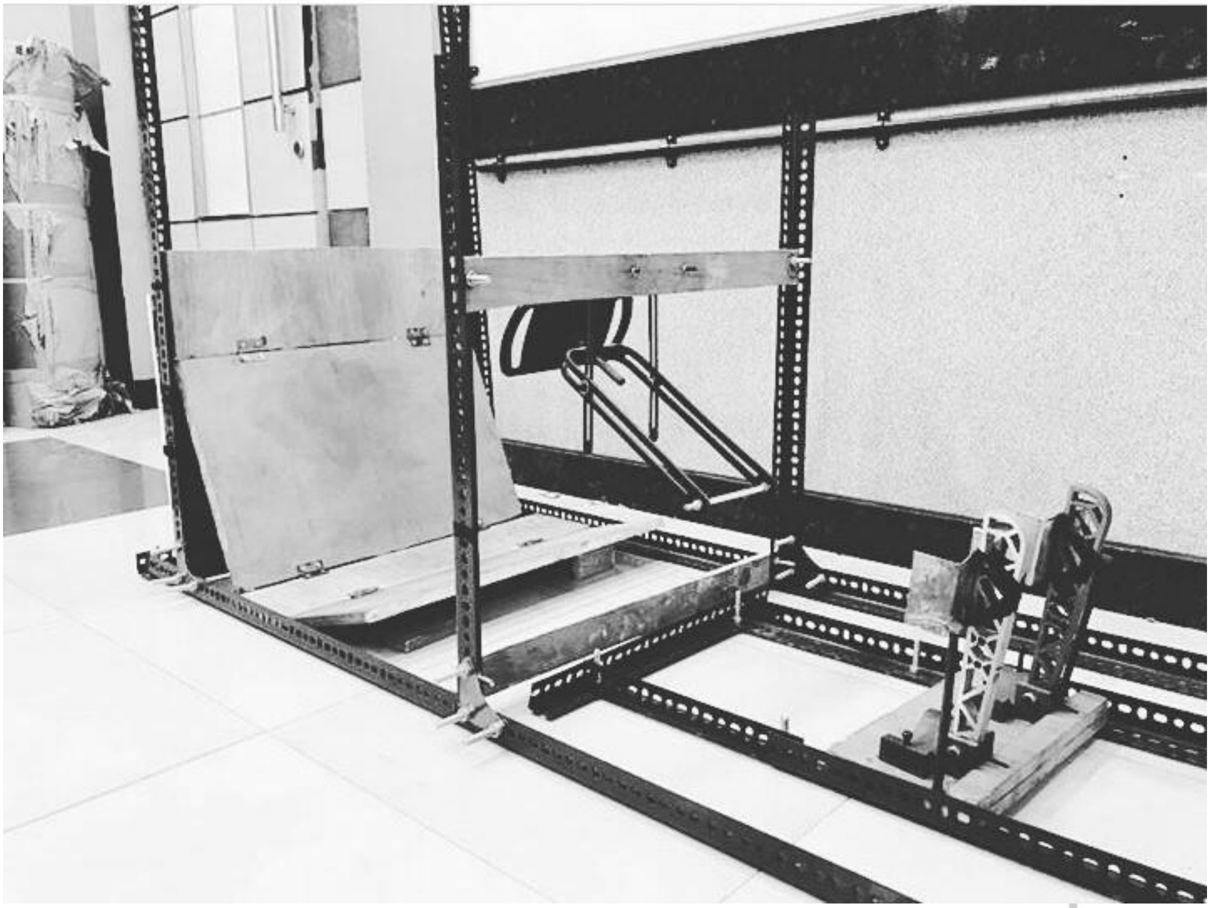
Whereas camber change on the inner wheel is approximately 5.5˚ when the wheel is turned by 30˚

4. Ergonomics

Ergonomics is a process of designing a race car so that it comforts the people who use it. It also helps to improve the driver interaction with the car. It's also up to us passengers and drivers to make ourselves comfortable. For instance, if you're a driver and position your seat so that your feet barely reach the pedals, you may induce unnecessary strain on your arms -- just as sitting too close can cause leg or back pain. Seat position, posture and time spent in the car all can affect a person's health.

The ergonomics of a cockpit of any vehicle is crucial. If the vehicle controls are not strategically placed, the operator will have difficulty operating the vehicle and the vehicle will not be capable of reaching peak performance. The safety of the driver could be in jeopardy if controls are not readily accessible.

Ergonomics study was performed in order to determine driver positions. By analysing and sitting in the previous car 03, critical driver positions were listed seat back angle, steering location, dash height, with of the cockpit, pedal height and shifter location. Then an ergonomics apparatus was designed (as per the above image) and built with each of the above dimensions adjustable. In order to take meaningful data a control variable was set.



For example, if the sit back angle is reclined the drivers will need a closer steering wheel along with the dash. Because the driver's eye heights are lowered with a reclined seat, the height of the dash becomes an issue of driver's visibility. The seat thigh angle determines the location of pedal assembly. As the seat thigh angle is inclined the driver will need the pedal assembly higher and closer. Since lowering the overall center of gravity of the car may increase lateral acceleration, the seat back angle was set to **50 degrees.**

Goals for ergonomics of the steering wheel:

- The drivers grip the steering wheel so that their upper arm and fore arm are at approximately at 90 degrees angle for best mechanical advantage while steering.
- The drivers can turn the wheel without hitting their legs with the wheels or their hands.
- The drivers can move their legs while operating the pedals without bumping the steering wheel in the process.
- The steering wheel stays within the height of the dash for rule compliance.
- The driver can see at least 20 feet ahead to the ground for reasonable visibility as specified by the drivers.

Aim:

The main aim of constructing and ergonomic setup for the steering wheel is to overcome the drawbacks of the previous design.

The drawbacks of previous steering wheel were:

1. Discomfort in holding the steering wheel for long time.
2. More effort required to steer the steering wheel

Design:

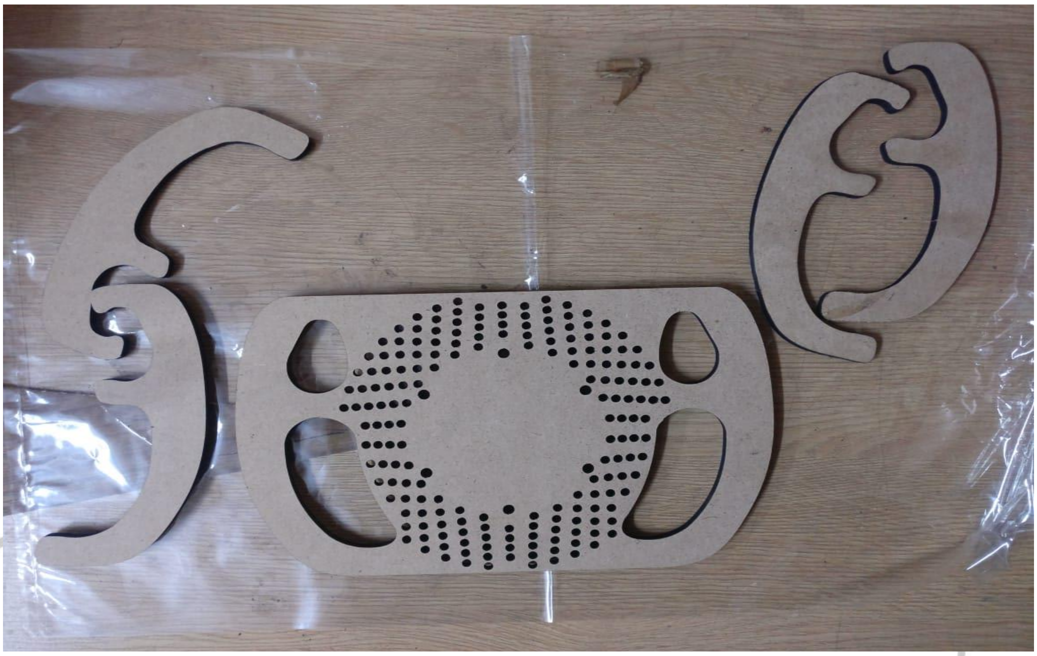
The setup was designed to determine inclination angles and distances of the steering wheel for different drivers. The angles that were to be determined were.

1. Inclination of steering upper column with the vertical
2. Distance between the steering wheel and the ground
3. Perpendicular distance between the UV joint and the FRH
4. Perpendicular distance between the steering wheel and FRH

The setup was designed within the chassis ergonomic structure with different parts for the steering wheel, upper column, and V-joint.

Assembly

For better adjustability of angles various parts were hinged together. The setup was bolted to chassis ergonomic structure at the top most position acting as a hinge.



Manufacturing

MDF (medium density fiberboard) was chosen as the material for the setup. MDF was selected for its durability and good machinability. 3 different steering wheels were finalized with different dimensions and numerous positions for the placement of the button and then the different parts were cut with the help of water jet cutting so that the setup was dimensionally accurate. After the size was confirmed from the driver another dummy wheel was designed from that size and similarly using laser cut, handles were manufactured of this same material. So, to provide proper grip and rest space for the palm the handles were given shapes using the clay and the one which was most comfortable was chosen and was implemented in the final design.

Methodology

The test was conducted by seating each driver in the setup and then adjusting the angles and distances of the setup to ensure their comfort. The angles were measured with the help of wooden blocks having pre-determined dimensions. The distance of the blocks from the hinges gave the inclination of the steering wheel. Multiple tests were conducted on the different drivers till optimum measurements were obtained that suited all the drivers.

Results

Name of Driver	Parameters Measured	Measurements
Harshil	Inclination of steering upper column with vertical(θ)(Degree)	24
	Distance between centre of steering wheel and ground(p)(mm)	393
	Perpendicular distance between uv joint and FRH(a)(mm)	200
	Perpendicular distance between FRH and steering wheel(b)(mm)	183
	(h)(mm)	175
	Distance between top most position of FRH and steering(q)(mm)	313
Prayank	Inclination of steering upper column with vertical(θ)(Degree)	30
	Distance between centre of steering wheel and ground(p)(mm)	
	Perpendicular distance between uv joint and FRH(a)(mm)	
	Perpendicular distance between FRH and steering wheel(b)(mm)	167
	(h)(mm)	138
	Distance between top most position of FRH and steering(q)(mm)	353
Ruchit	Inclination of steering upper column with vertical(θ)(Degree)	30
	Distance between centre of steering wheel and ground(p)(mm)	
	Perpendicular distance between uv joint and FRH(a)(mm)	
	Perpendicular distance between FRH and steering wheel(b)(mm)	167
	(h)(mm)	138
	Distance between top most position of FRH and steering(q)(mm)	353
Rachit	Inclination of steering upper column with vertical(θ)(Degree)	24
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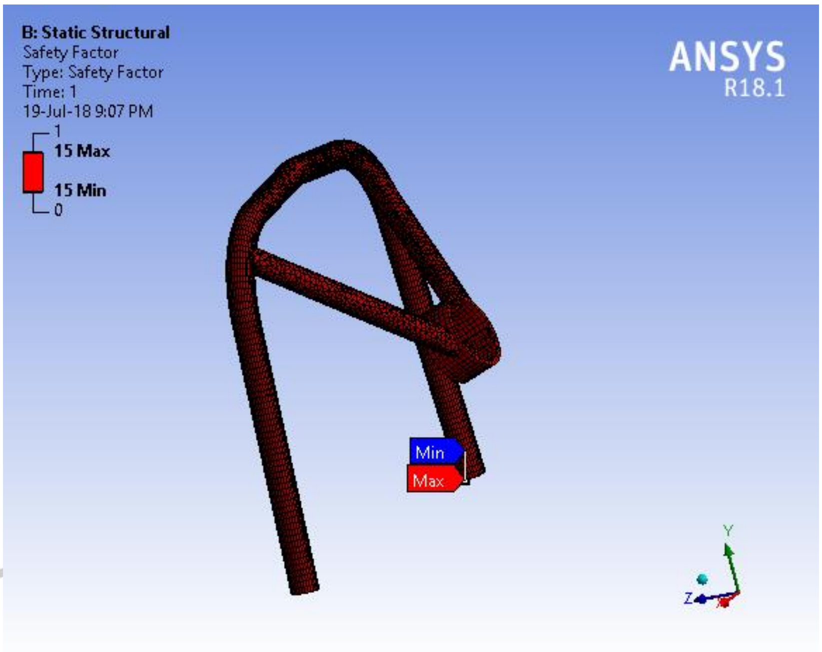
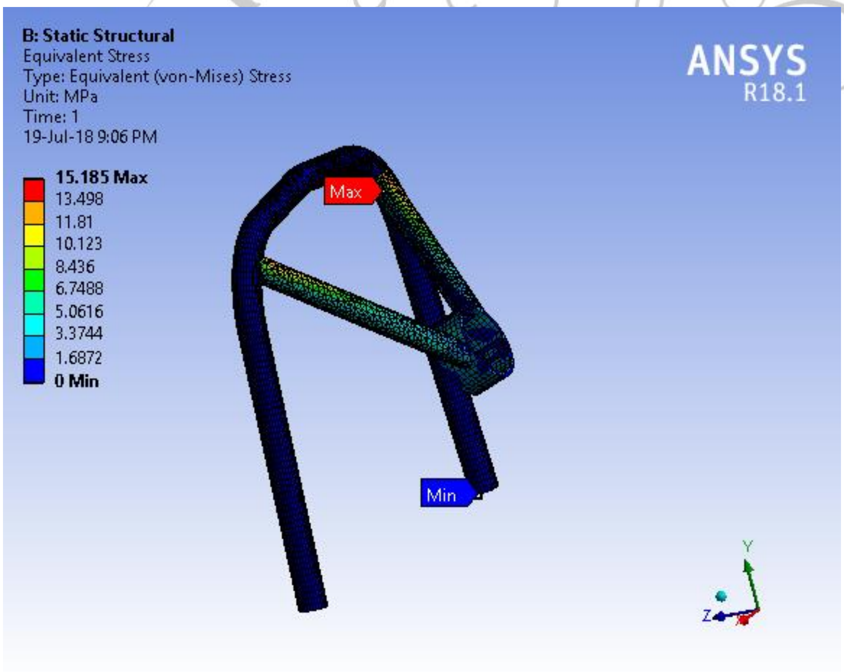
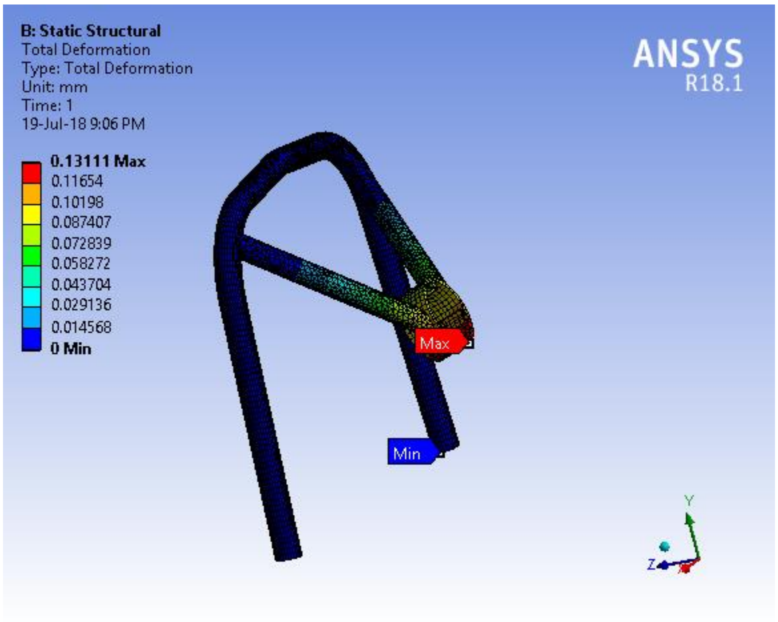
	Perpendicular distance between FRH and steering wheel(b)(mm)	183
	(h)(mm)	175
	Distance between top most position of FRH and steering(q)(mm)	313

5. Upper Assembly

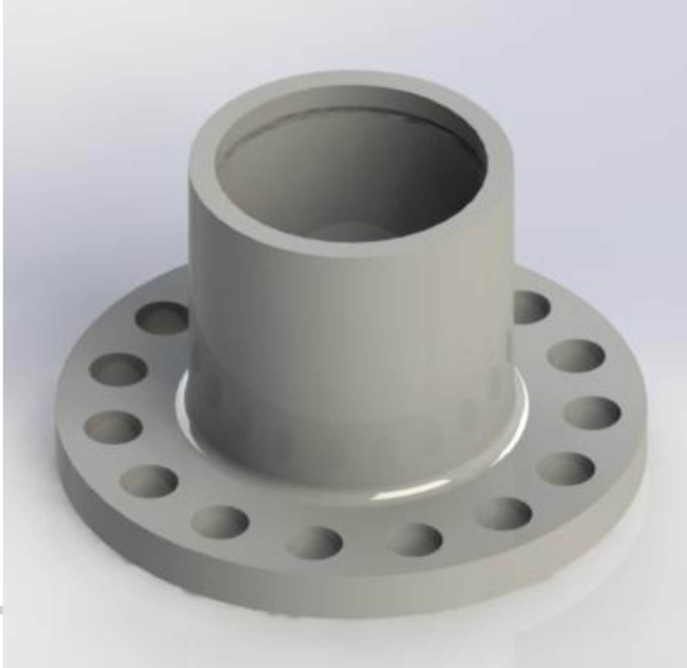
5.1 Steering Mount:






B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
19-Jul-18 9:06 PM
0.13111 Max
0.11654
0.10198
0.087407
0.072839
0.058272
0.043704
0.029136
0.014568
0 Min
ANSYS
R18.1
Max
Min
Y
Z

5.2 Hub:



Concept:

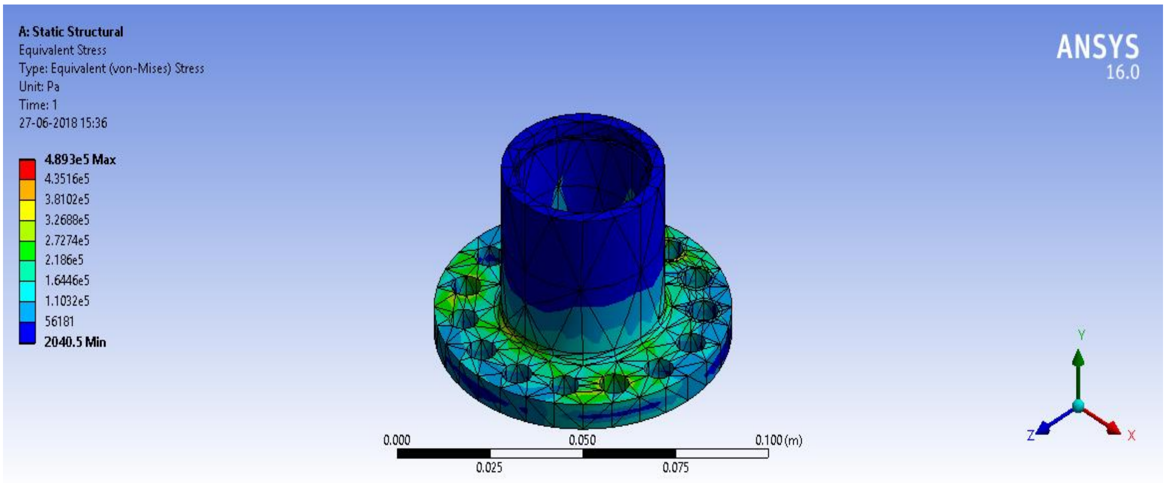
It is bolted to the hub with bolts each at the angle of 120 degrees to each other. The circlip is grooved into the hub which helps the rotary motion of the upper column. It also houses the bearing.

Design:

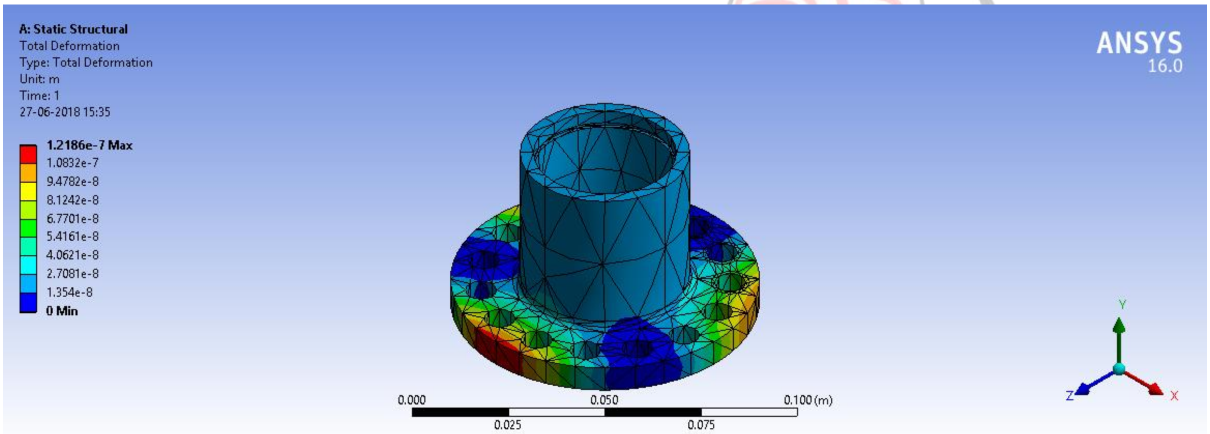
The bearing for the column has a bore diameter of 20mm, outer diameter of 37mm and is 30mm overall in length. The hub is made of Al 6082 and houses the needle bearing. Fifteen circular slots of diameter 8mm are made to reduce weight. It approximately weighs 117.15 grams.

Analysis:

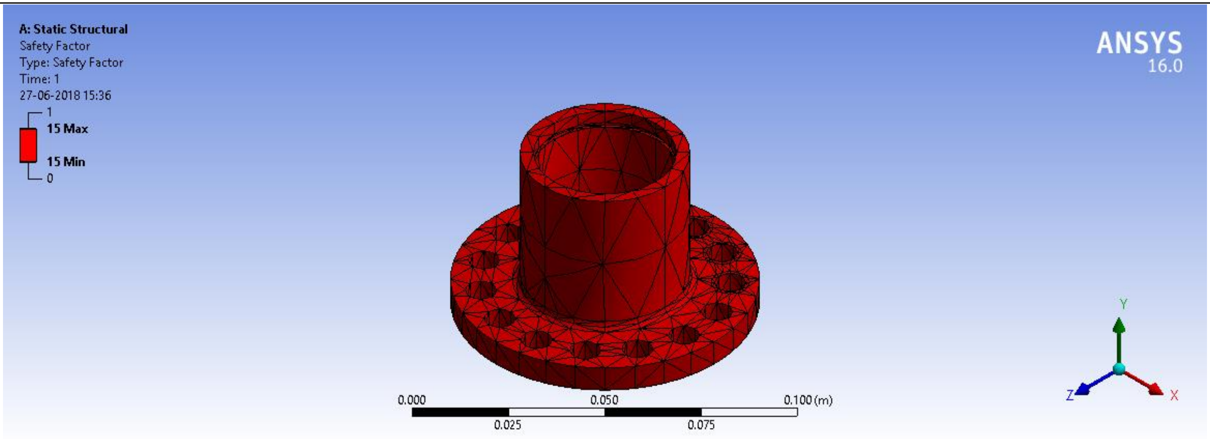
Equivalent Stress:



Total Deformation:



Factor of Safety:



Manufacturing:

A raw material of diameter 85mm and length 50mm of Al 6082 was procured.

Process used:

1. Turning
2. Drilling

Process setup: The process consisted of 2 setups:

a. The process was performed on the conventional lathe machine.

b. Turning was done to make the job of required outer and inner dimensions.

c. Drilling was performed to drill those 8 holes symmetrically.

5.3 Steering Wheel:

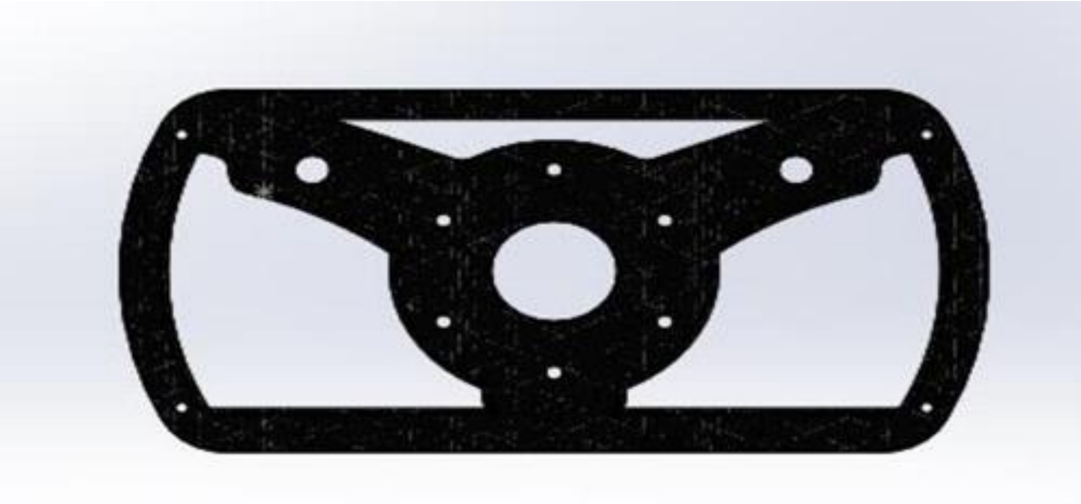
CONCEPT:

The steering wheel is the critical interface between driver and car. From here, through the use of various buttons he can make numerous changes to his machine - all without ever having to lift off the throttle.

DESIGN OBJECTIVES:

The steering wheel was designed ergonomically by taking the inputs from the drivers. This was one of the major objective of this year's design making it easy for him to get proper grip. The introduction of semi-automatic gear changes, operated via the now familiar 'paddles' on the back of every steering wheel, marked the beginning of the move to concentrate controls as close to the driver's fingers as possible. This was also an update compared to the previous design. The clutch is also operated by a similar paddle. The first thing which we kept in mind while designing the steering wheel was that it should have sufficient amount of force arm so that it would be easy for the driver as he has to apply less force to turn the steering wheel to apply a proper amount of torque but also to keep in mind that the force arm doesn't exceed above a limit after which the steering wheel would hit the drivers leg and which would compromise driver comfort.

Steering Wheel 1.0:

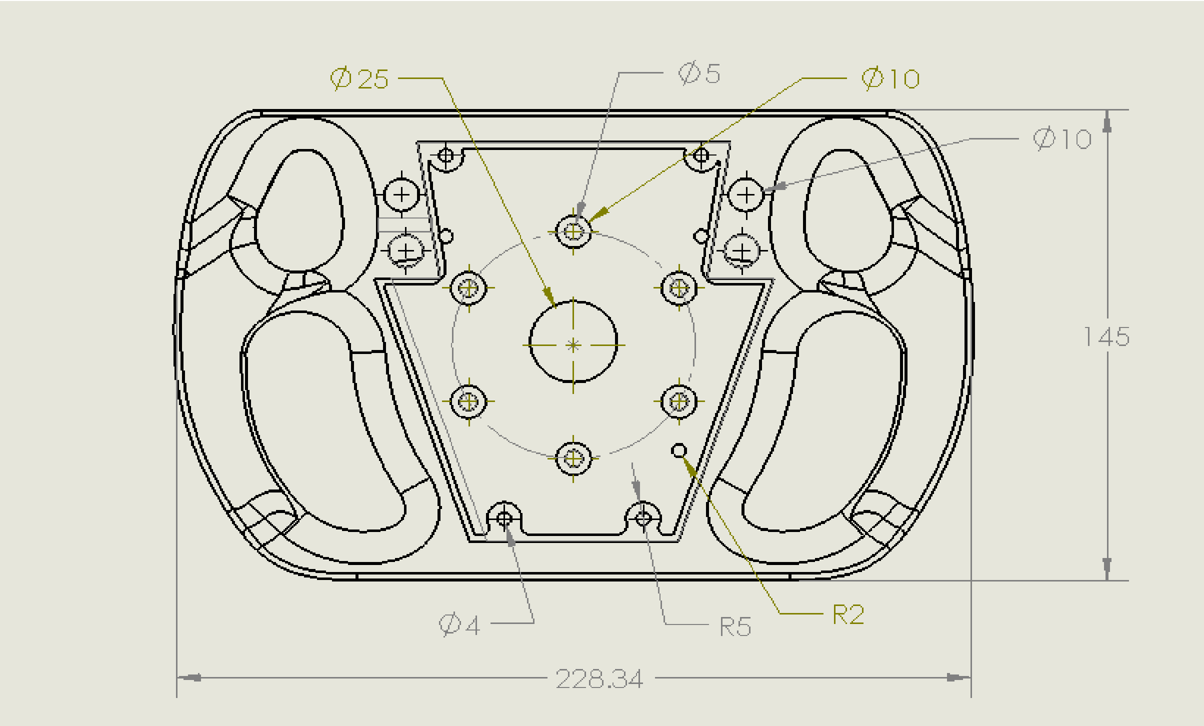


This steering wheel design had a lot of slots in it as the previous year's design was overdesigned but due to the difficulty in manufacturing of such slots, this design was not feasible as it could lead to breaking of the wheel during slot cutting and hence it was not used.

Steering Wheel 2.0:

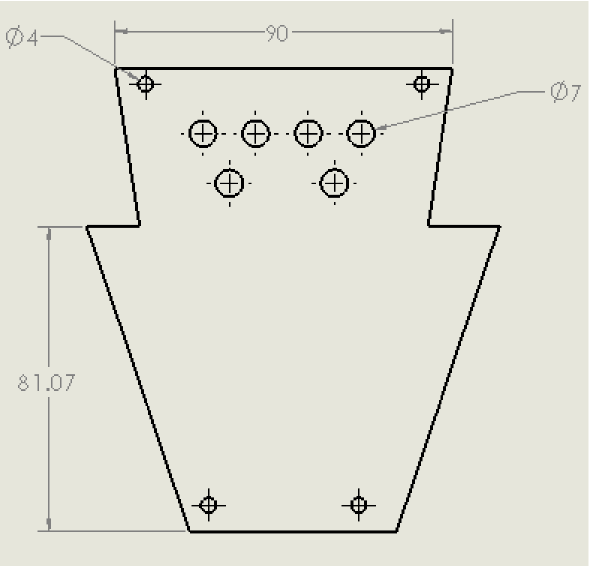
This steering was made up of carbon fiber and hence required a mould which made manufacturing it slightly difficult and it also wouldn't accommodate electronics which we require in this year's car hence a new design was made.

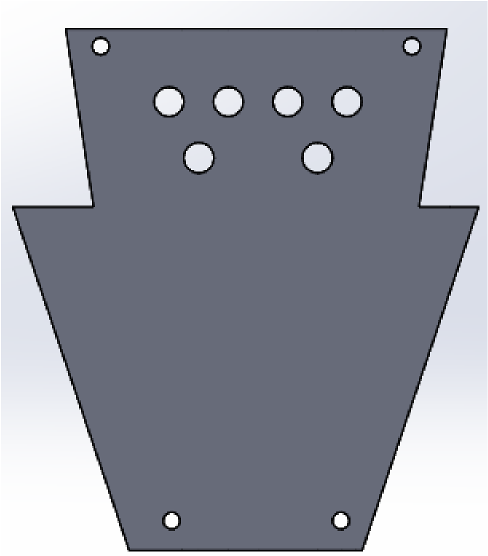
Steering Wheel 3.0:



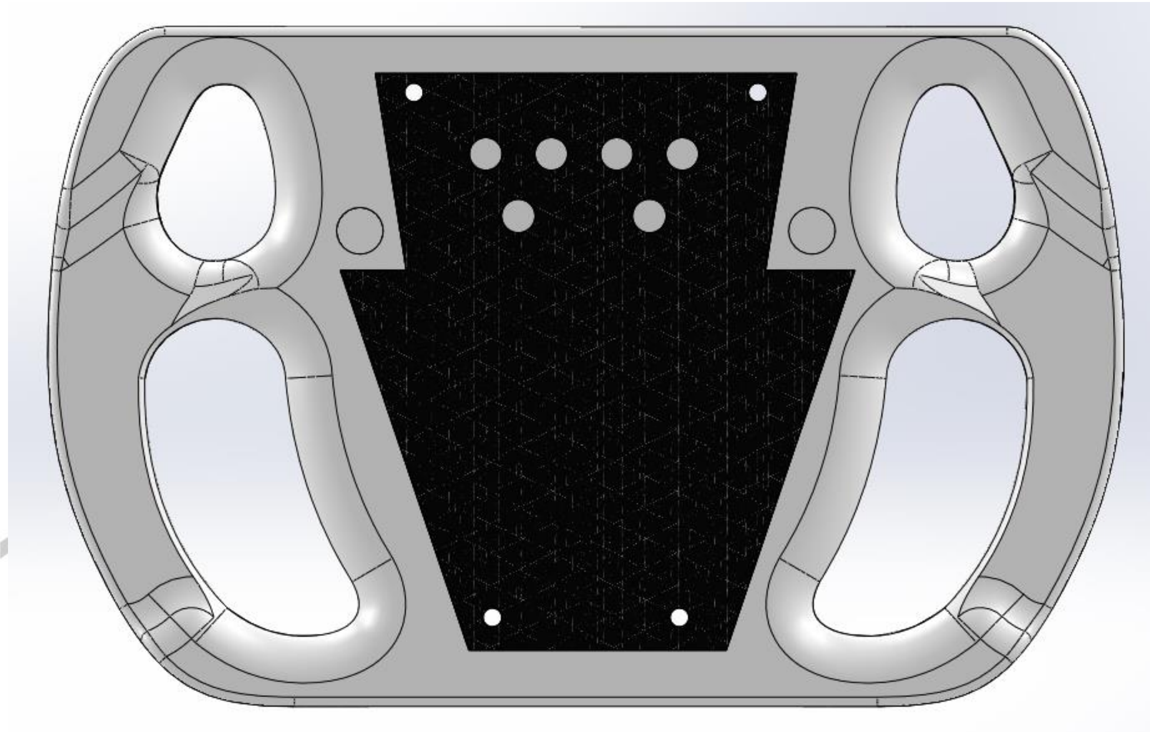
The Steering wheel for this season was 3D Printed from ABS. This made the manufacturing process much simpler. Last year, wheel was made out of CF which required moulds and the incorporation of electronics was very difficult. In this design it is also easy to incorporate electronics as the central part provided is hollow. The hand impressions of the driver were also taken and then the 3D printing was executed. The process which was used was FDM providing 80% of infill. The steering wheel also incorporates Clutch pedals and pneumatic shifter pedals.

CF PLATE:





The plate is made up of carbon fiber because it is more durable and light weight. The carbon fiber plate undergoes water jet operation according to the dimensions of the plate decided. CF plate is then bolted on the steering wheel by four M4 bolts. There are six holes of diameter 7 which are provided for LED lights. They would indicate the amount of revolutions per minute (rpm) that the car has which would glow when the range is from 3000 to 10000. This plate can also be utilized as a cover for wires and other electrical connections which are inside the steering wheel.



5.4 Quick Release and Quick Release shaft:

A quick disconnect is provided on the steering wheel which is connected to the QR shaft which is welded to the column. It was made sure that it provides ‘Zero Play’ condition. This Quick release was chosen because it provides a neat and clean electrical connections. It helps in passing electrical wires through it and hence avoids the wires lagging around in the cockpit.

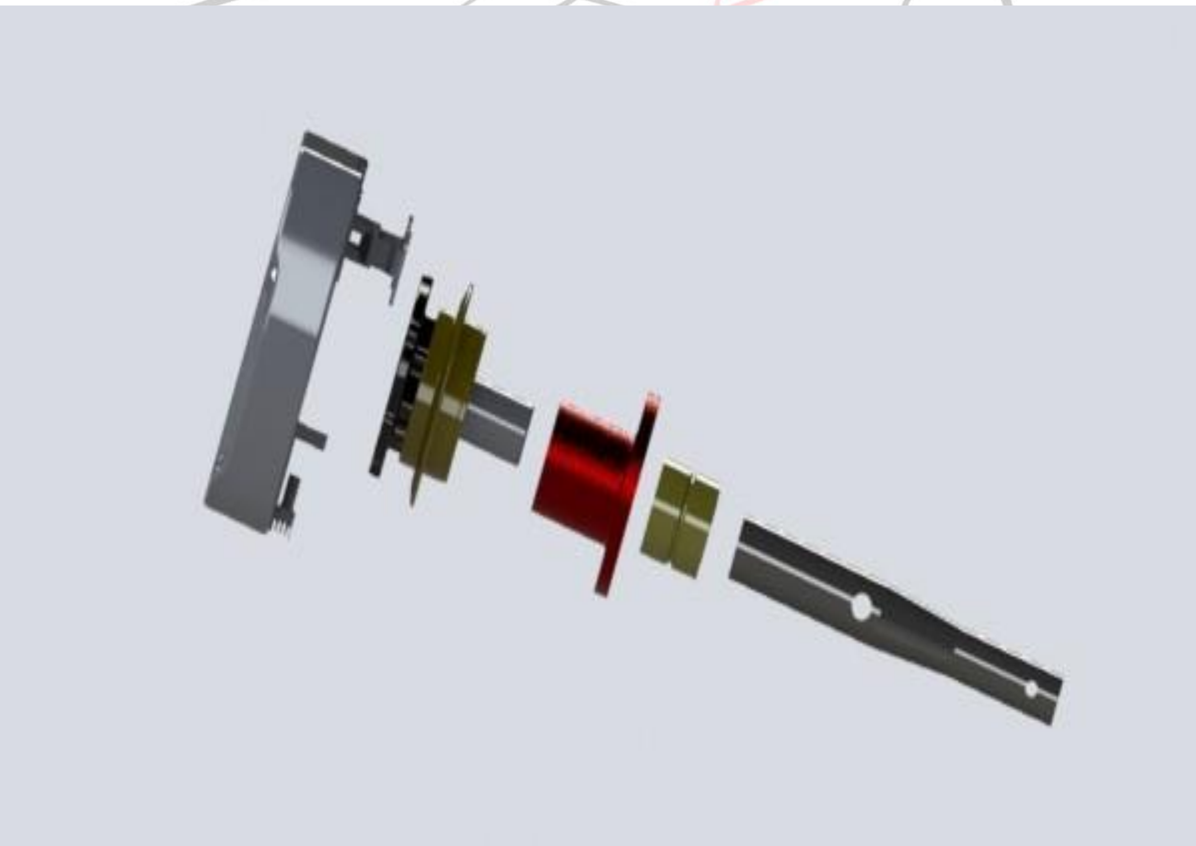
This was not manufactured by the team and was purchased from KRONTEC.

Model No. : QR03-22P

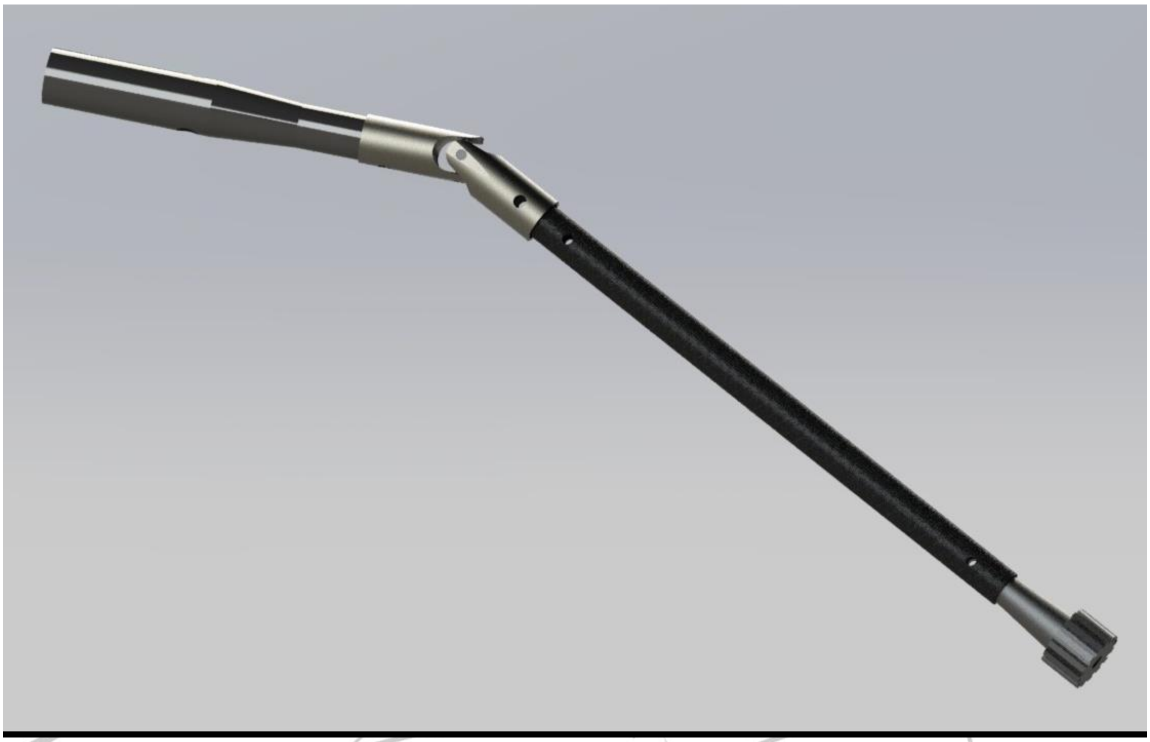
The weld-on section (welds to your column) is both tear-shaped and tapered depth-wise. The result - it centers the wheel perfectly and easily. It glides the wheel on the column. And the locking mechanism both clearly defines when the wheel locks on, and provides a 100% positive-lock so it cannot come off unintentionally.

The Shaft was welded with upper column of the column assembly and was used to transmit the connection of the wire which came from the Dash through the column. When the steering wheel was connected to this shaft the electrical connections would automatically get connected and the need of wire to make the required connections on the steering wheel which was the case in last years car was successfully eliminated.

Upper Column Assembly:



6. Column Assembly



The column assembly consists of three parts namely:

6.1 Upper Column
6.2 Universal Joint
6.3 Lower Column

Concept:
The first thing kept in mind while designing the column was to bolt the column inside the universal joint and the outer diameter of the column was decided on the inner diameter of the universal joint which was 19mm. The inner diameter of the column was decided keeping in mind the maximum torque transmission capacity and accordingly have a proper weight reduction. The side view geometry was made keeping the cockpit templates and rules in mind and the length of the column was obtained from it. The main reason for using an alternate material i.e. carbon fibre for lower column was to provide high torsional rigidity to weight ratio.
Properties of CF:

- High strength to weight ratio
- High resistance to corrosion
- High torsional rigidity
- Resistant to fatigue

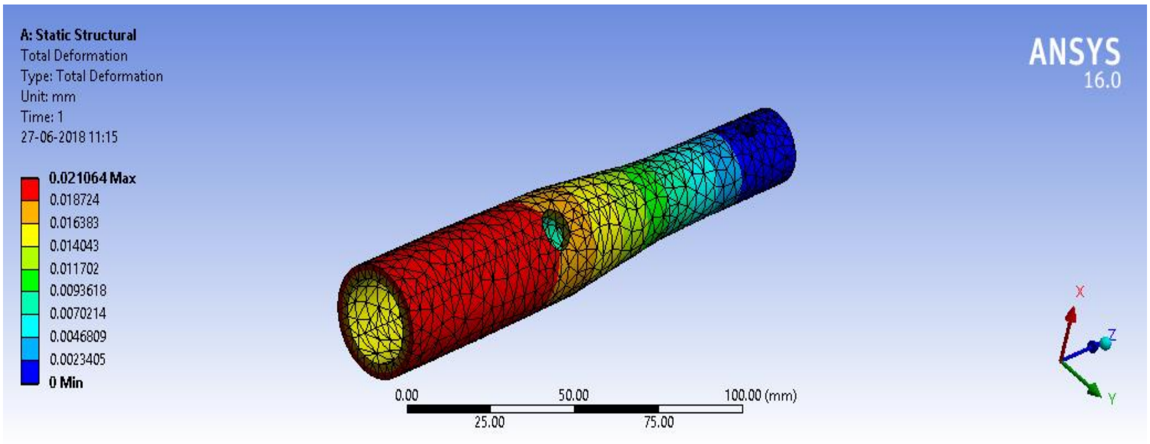
6.1 Upper Column :

Design:

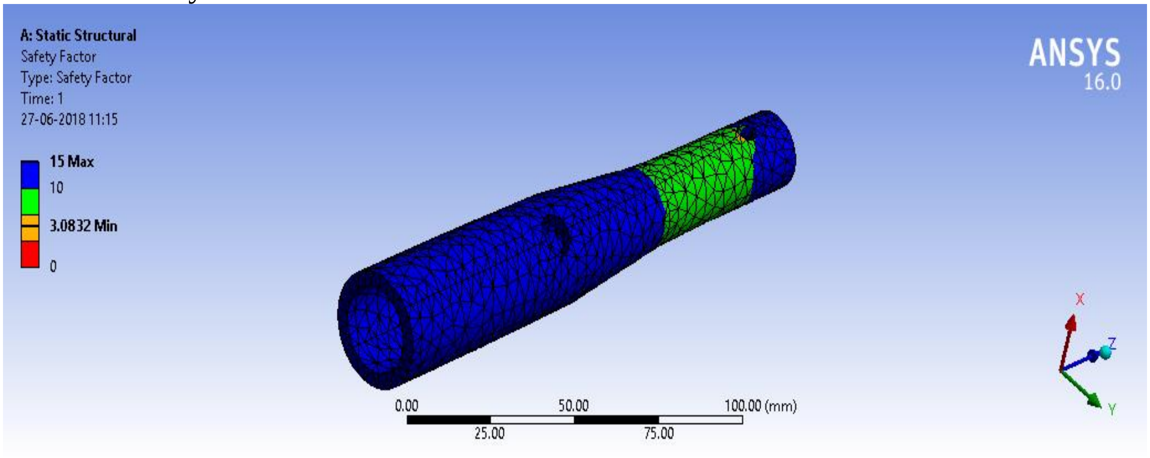
Upper Column is attached to the other end of the universal joint. It is welded to the quick release shaft along the circumference. A V butt joint was made to weld the two shafts. A fixture was made to hold them coaxially. The shaft is cross bolted to the universal joint. Two holes of diameter 10mm are provided for the wires which would come from Dash to pass through them and then they are connected to the connector of the Krontec QR shaft. The needle roller bearing is press fitted on the outer surface. Overall weight of the column was 316.92grams

Analysis:

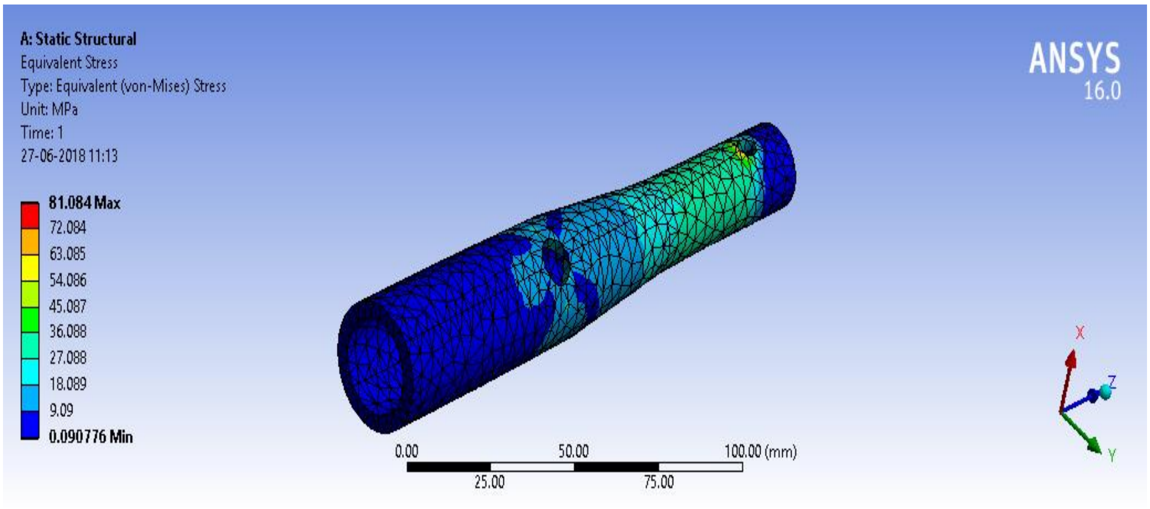
Deformation:



Factor of safety:



Equivalent stress:



Manufacturing:

A hollow material of EN24 was procured having outer diameter 25.2mm and inner diameter 13mm. Length of the material being 180mm.

Process used:

1. Turning
2. Drilling
3. Welding

The process was carried out in 3 stages:

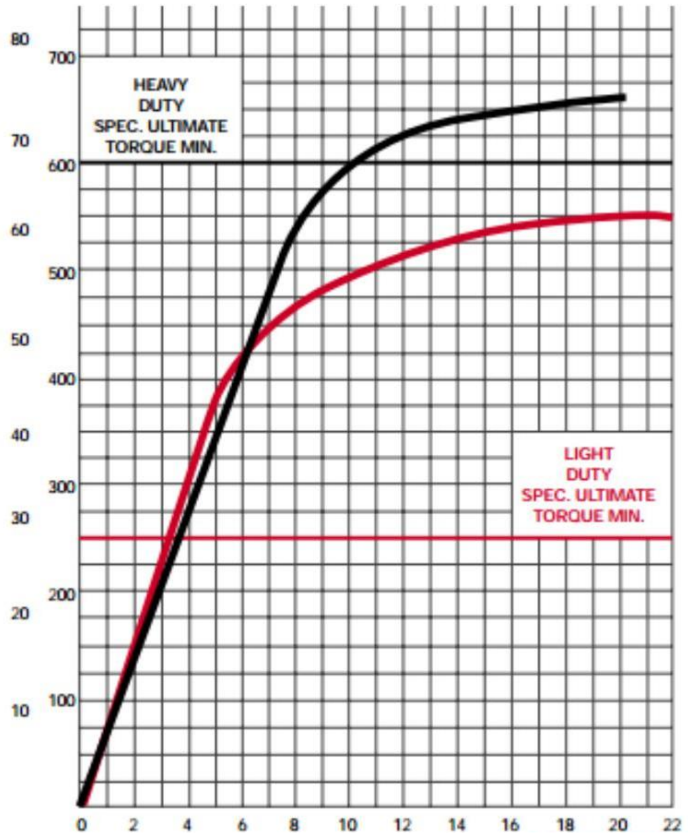
- Firstly the diameters were made to size by proper turning operation and tapering operation was performed using the same tool turning center. The coolant used was cutting oil.
- A hole was drilled through and through at the bottom for insertion of bolt for the universal joint.
- The upper column is then welded to the QR shaft.

Universal joint:

The universal joint was not manufactured by the team. It was procured from Apex.

The joint is made of alloy steel and is capable of withstanding high torque. The universal joint is covered with a silicone rubber boot to prevent dirt from contaminating the lubricant. It has a hardness of 40 HRC.

The black curve indicates the deflection curve of the joint.



The universal joint is not a constant velocity joint. The operating angle of universal joint was increased from 25 to 30 keeping in mind the maximum operating angle of universal joint, this was done because when the operating angle was 25 the mount needed was much larger which would hit the drivers leg resulting into bad ergonomics and also the mount would cantilever under the application of force and hence it was changed to 30 degrees.

When the axes are at an angle, input shaft is moving at a constant speed, in this case both the input and output shafts turn in different planes and as a result the shafts turn at different speeds.

Consider shafts a and b inclined to each other at an angle β and let the velocity of input shaft be constant therefore,

the output shaft velocity= {(input shaft velocity) *cosβ} /{1-(sinα*sinα*sinβ*sinβ)}
where α is the angular displacement.

Shaft Speed Ratio:

The output shaft velocity= {(input shaft velocity) *cosθ} / {1-(sinα*sinα*sinθ*sinθ)} where θ is the angular displacement and α is the angle at which both shafts are inclined to each other

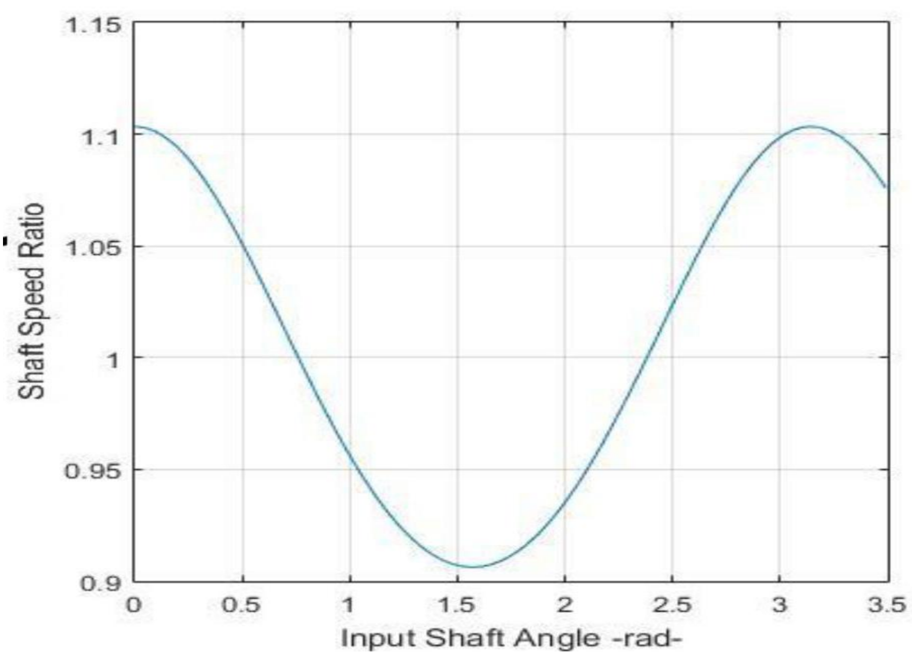
The instantaneous velocity of the output shaft can be compared to the input shaft. 25˚

Inclination was taken into account for the first iteration of column layout. 30˚ was the second iteration.

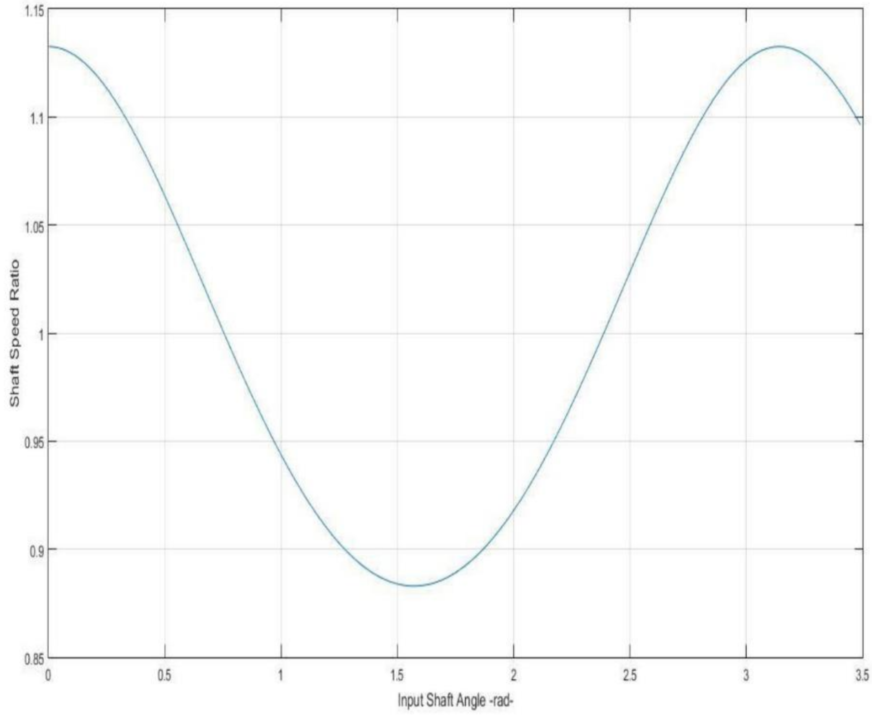
Code:

```
Alpha =30*pi/180;      %%insert inclination angle%%
 for i=1:2000
theta (i)=0.1*i*pi/180;
k(i)= (cos(alpha)/(1-(cos(theta(i)))*(cos(theta(i)))*(sin(alpha))*(sin(alpha))));
end
plot(theta,k);
grid on;
xlabel ('Input Shaft Angle -rad-');
ylabel ('Shaft Speed Ratio')
```

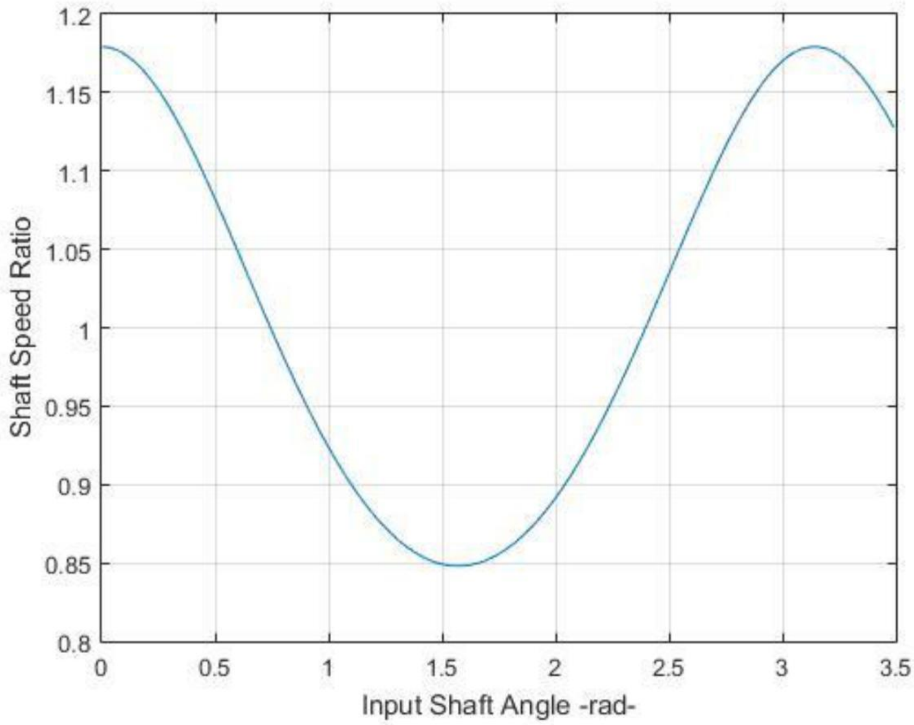
A.25



B. 28


1.15
1.1
1.05
1
0.95
0.9
0.85
Shaft Speed Ratio
0
0.5
1
1.5
2
2.5
3
3.5
Input Shaft Angle -rad-

C.32


1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
Shaft Speed Ratio
0
0.5
1
1.5
2
2.5
3
3.5
Input Shaft Angle -rad-

The graph indicates a 15% increase in shaft speed initially and varies up to a 13% decrease in shaft speed from 0˚ of steering wheel deflection to 90˚ of steering wheel deflection. This will give the driver better control on entering a sharp turn and a quicker response on exiting the turn.

Machining:

- Drilling
  A through hole of 6 mm was drilled to mate it with Upper column.
  Another hole of 8 mm was drilled to mate it with UV insert of Lower column.

6.2 Lower Column:

Design:

The main reason to design and manufacture a CF lower column and not MS lower column was to reduce the weight. It helped us achieve high torsional rigidity to weight ratio.

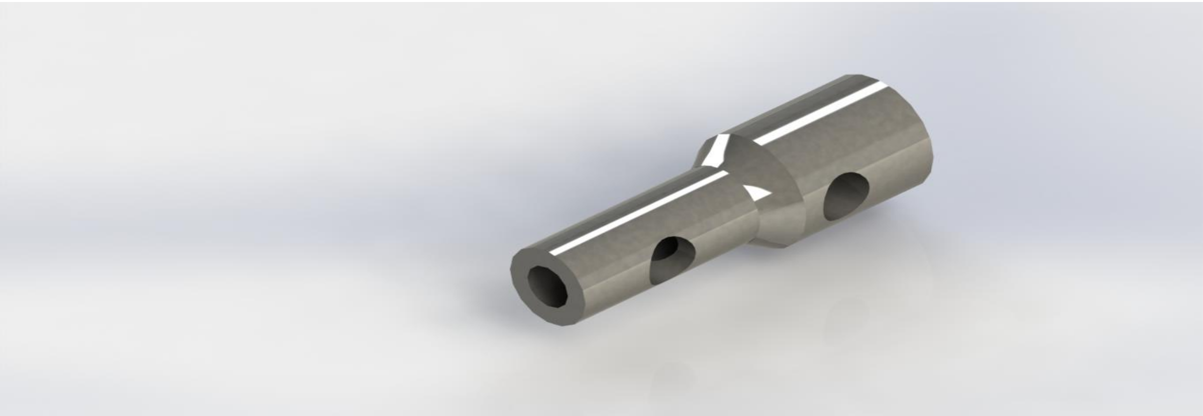
Lower column is divided into three parts:

6.3.1 UV insert.

6.3.2 CF Column.

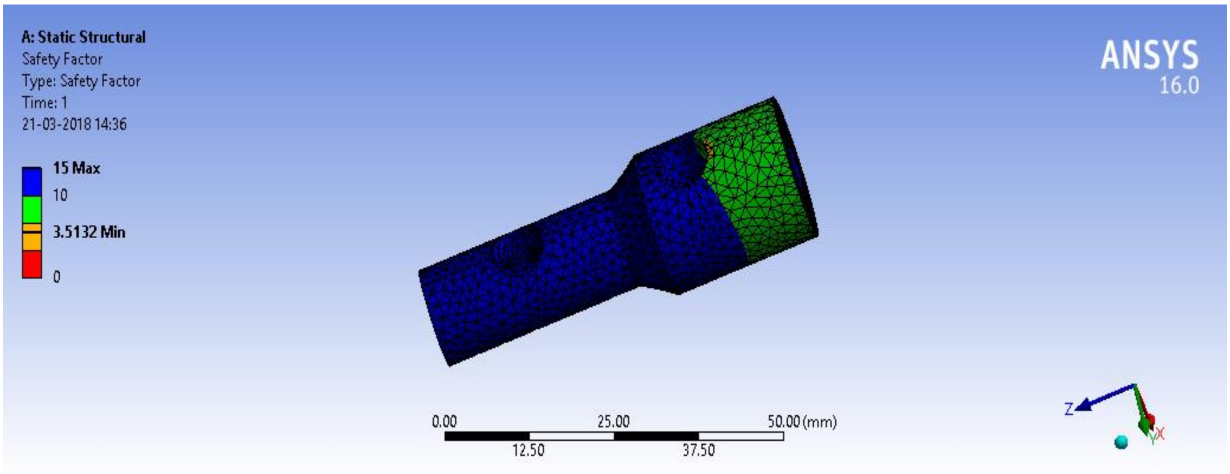
6.3.3 Pinion insert.

6.3.1 UV insert:

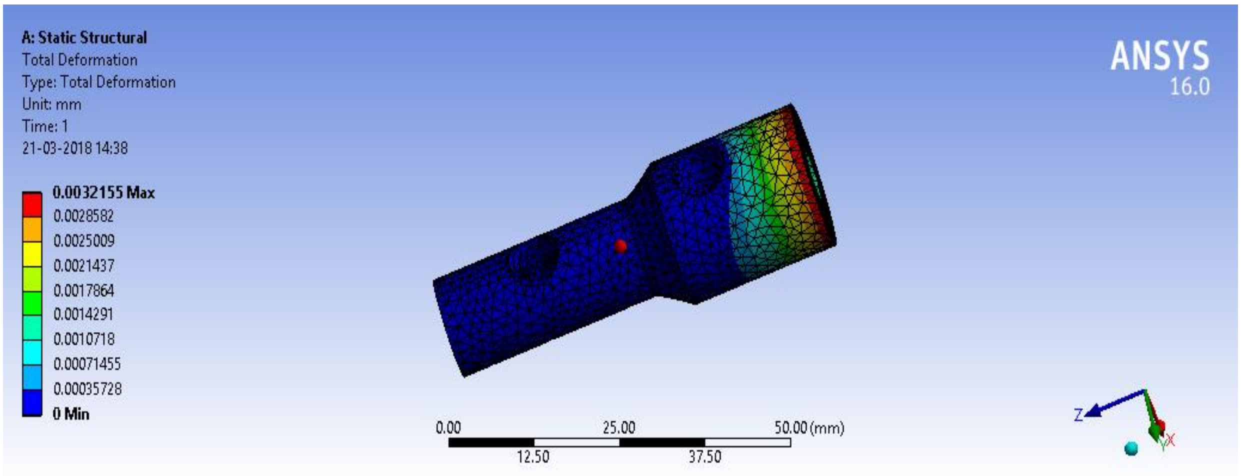


Analysis:

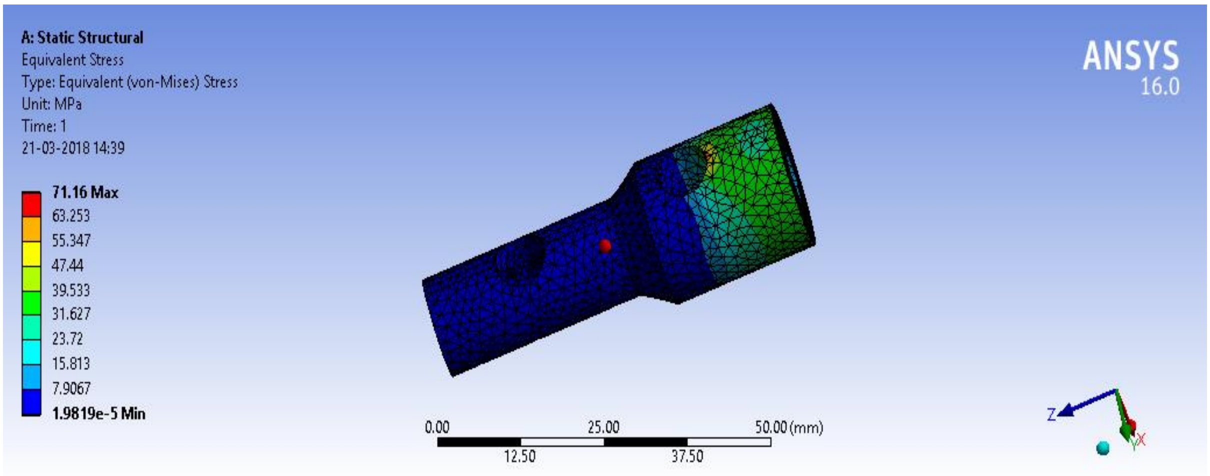
Factor of Safety



Total Deformation:



Equivalent Stress:



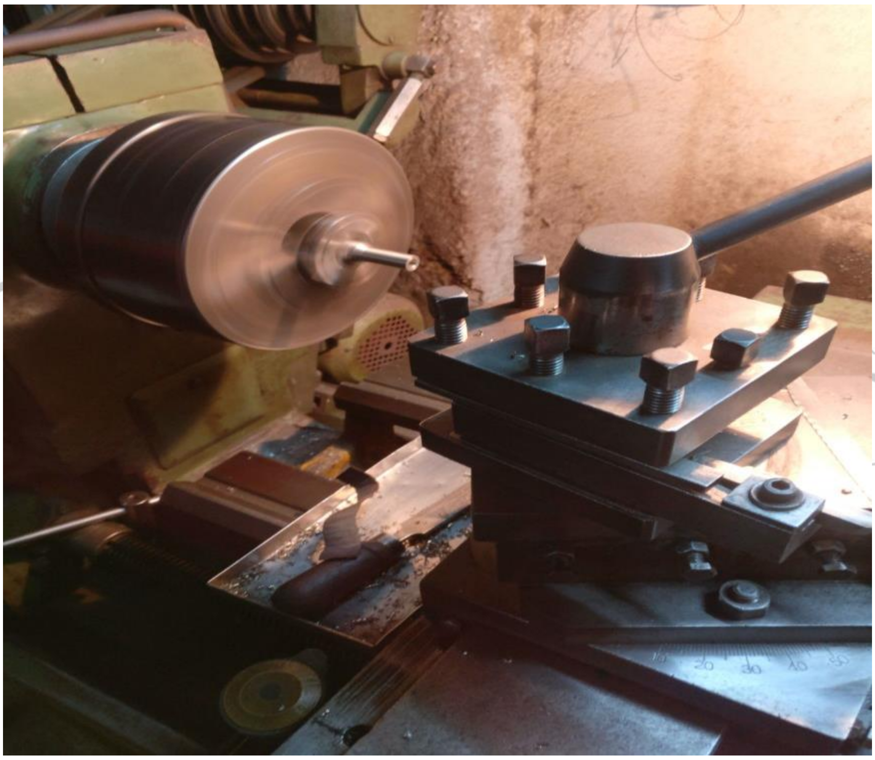
Manufacturing:

The UV joint insert was made up of material SS304 to prevent wearing as it is slide fitted in the UV. It weighs approximately 64 grams.

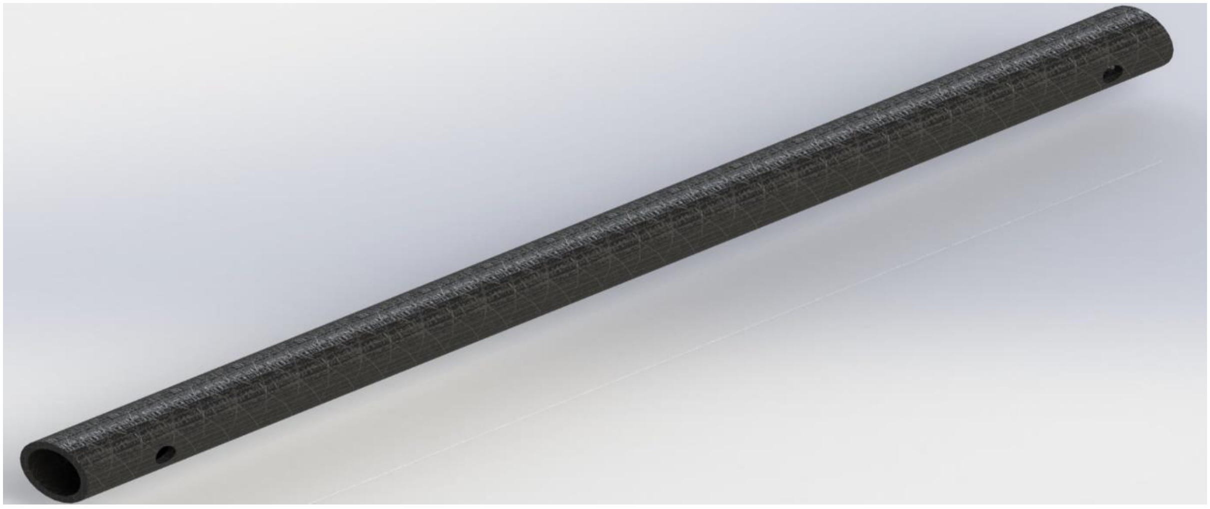
1. Turning
2. Drilling

The process was carried out in 2 steps:

- The insert initially was turned according to the design.
- A through hole of 8mm was drilled for the insert to mate with the UV joint.
- Another hole of 6mm was drilled to mate with CF column after being bonded.



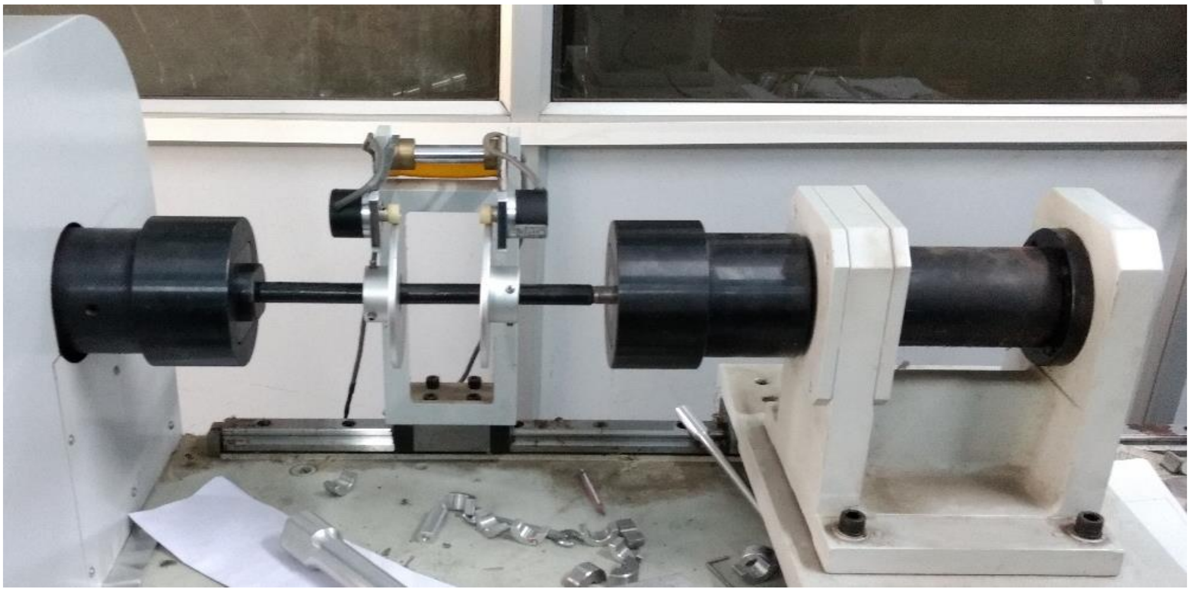
6.3.2 CF column:

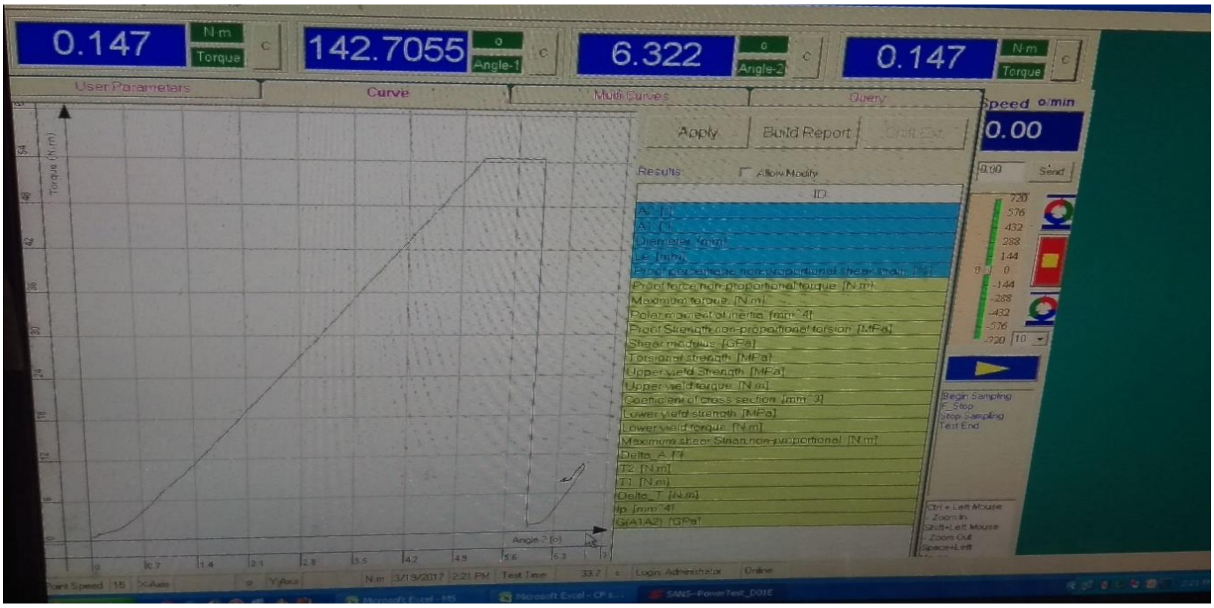


A hollow CF rod was procured having outer diameter 17mm and inner diagram 13mm, length being 268. Both the inserts are bonded to the CF column using Loctite 120Hp and a provision for mechanical fastening was provided so that in case of bond failure, there is no system failure.

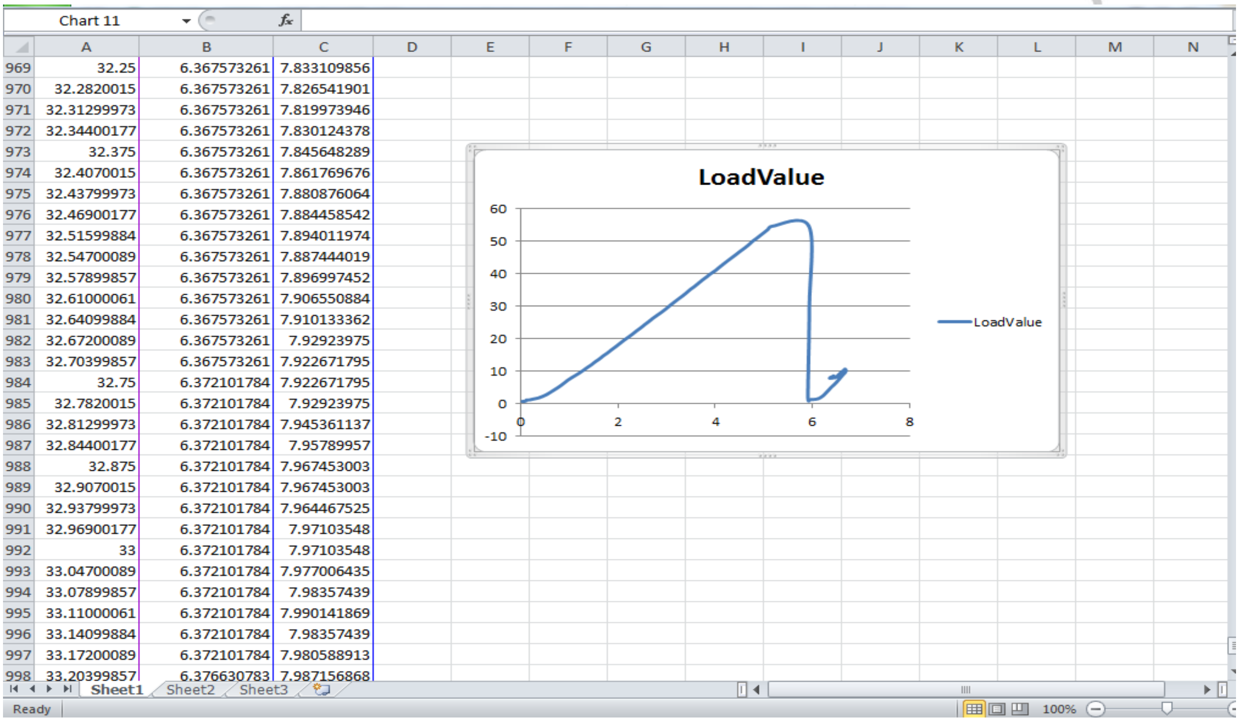
Testing Lower column:

Torsional rigidity test was performed to check whether it can withstand the torque applied to it or not.





We found that the bonding between CF and its insert failed at 54 N-m which is under the limit of the maximum force developed by the tires and hence the CF column could be used.
The UV joint insert is made up of EN24 with splines made on both the insert as well as pinion and then they are slide fitted ad fastened through grub screw so as to reduce the play and thus meets the requirements. It has following {dimensions} with a step between the part which inserts between the rod and the splines for pinion with a slight amount of tapering before the splines after the step.



	A	B	C
969	32.25	6.367573261	7.833109856
970	32.2820015	6.367573261	7.826541901
971	32.31299973	6.367573261	7.819973946
972	32.34400177	6.367573261	7.830124378
973	32.375	6.367573261	7.845648289
974	32.4070015	6.367573261	7.861769676
975	32.43799973	6.367573261	7.880876064
976	32.46900177	6.367573261	7.884458542
977	32.51599884	6.367573261	7.894011974
978	32.54700089	6.367573261	7.887444019
979	32.57899857	6.367573261	7.896997452
980	32.61000061	6.367573261	7.906550884
981	32.64099884	6.367573261	7.910133362
982	32.67200089	6.367573261	7.92923975
983	32.70399857	6.367573261	7.922671795
984	32.75	6.372101784	7.922671795
985	32.7820015	6.372101784	7.92923975
986	32.81299973	6.372101784	7.945361137
987	32.84400177	6.372101784	7.95789957
988	32.875	6.372101784	7.967453003
989	32.9070015	6.372101784	7.967453003
990	32.93799973	6.372101784	7.964467525
991	32.96900177	6.372101784	7.97103548
992	33	6.372101784	7.97103548
993	33.04700089	6.372101784	7.977006435
994	33.07899857	6.372101784	7.98357439
995	33.11000061	6.372101784	7.990141869
996	33.14099884	6.372101784	7.98357439
997	33.17200089	6.372101784	7.980588913
998	33.20399857	6.376630783	7.987156868

6.3.3 Pinion insert:

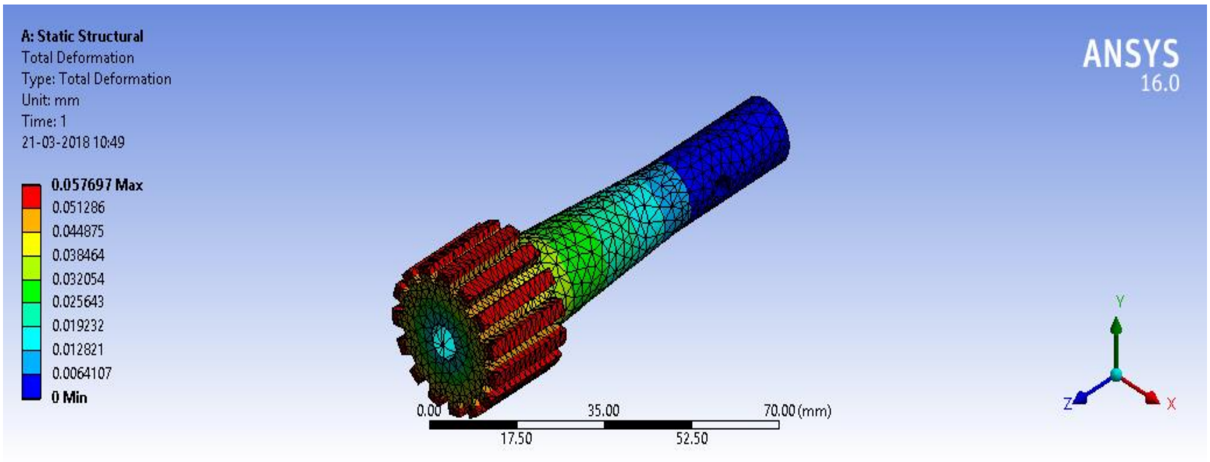
Design:

This insert connects to the pinion. It is connected to the pinion shaft by means of bolting however this method of bolting alone caused a play in the system. In present design splines are made on both the pinion insert and the pinion and then they are slide fitted and fastened through a grub screw as a result of which the play was reduced to a huge extent and torque transmission was up to the requirement.

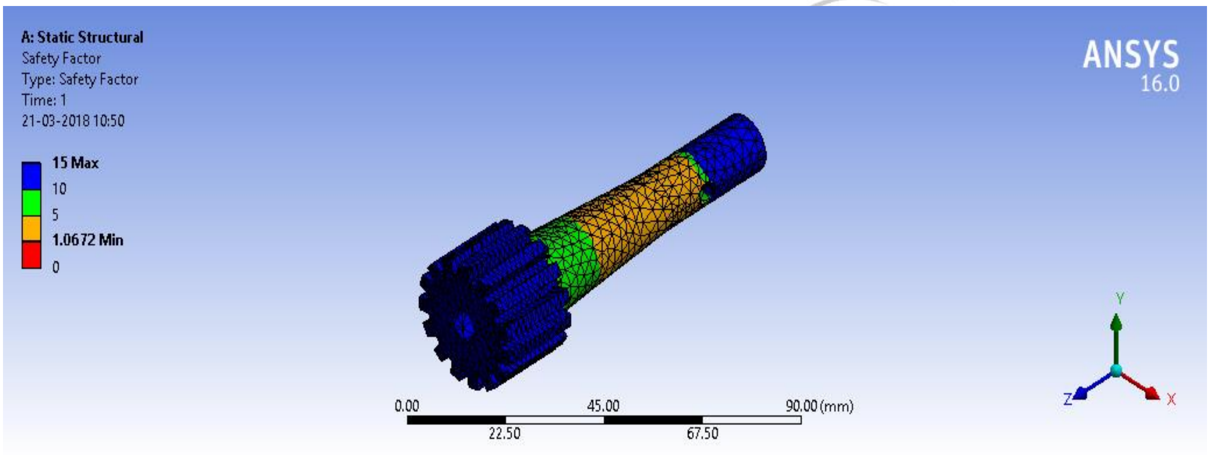
A taper was given before the start of splines to prevent stress concentration at a particular area due to sudden change in diameter. A bearing is press fitted between the pinion insert and the housing to provide smooth rotatory motion. It was hardened to 45 HRC so as to reduce the wear due to hardened bolts. It weighed approximately 151grams.

Analysis:

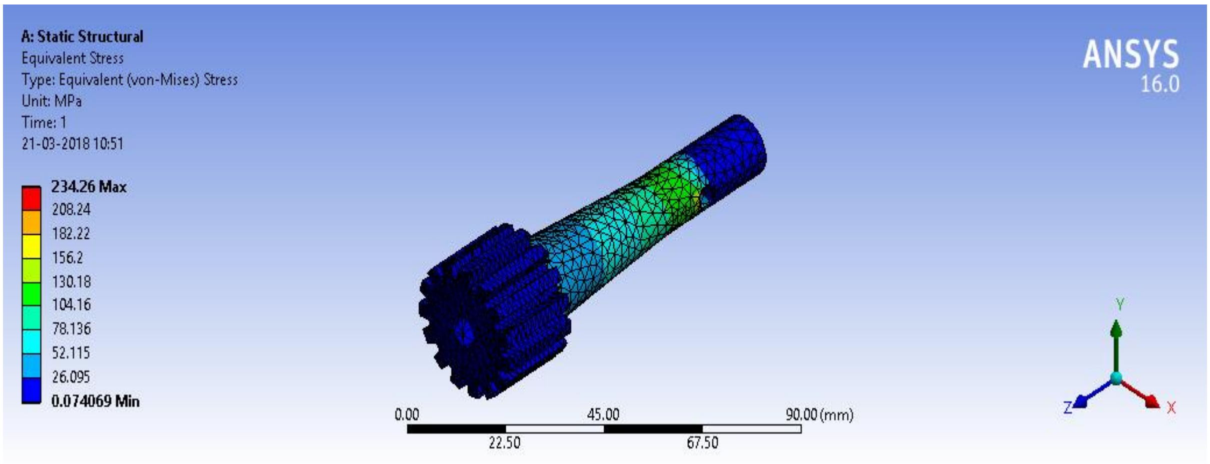
Total Deformation:



Factor of safety:



Equivalent Stress:



Manufacturing:

A hollow material of EN24 was procured having outer diameter 31mm and inner diameter 7mm. Length of the material being 100mm.

The pinion insert is made up of EN24 so as to avoid chip formation due to wearing as it is to be mated with the pinion which is of EN24.

Process used:

1. Turning.
2. Gear hobbing.
3. Drilling.

The process was carried out in 3 stages:

- Firstly the diameters were made to size by proper turning operation and tapering operation was performed using the same tool turning centre. The coolant used was cutting oil.
- The splines were created on the outer periphery of it using the gear hobbing process using a mill form cutter.
- A hole was drilled through and through at the top for insertion of bolt for the universal joint. Another hole was drilled and tapped up to a length of 5mm for insertion of grub screw. Lastly it was hardened at 35 HRC and then powder coated.

Lower Column Assembly

7. Lower Assembly:

7.1 Base Plate:

Concept:

The function of base plate was to support the entire assembly of the steering system below the mount assembly rigidly along with the chassis to eliminate any compliance. To achieve this various iterations were performed and out of which the design with minimum weight and optimum amount of strength was used.

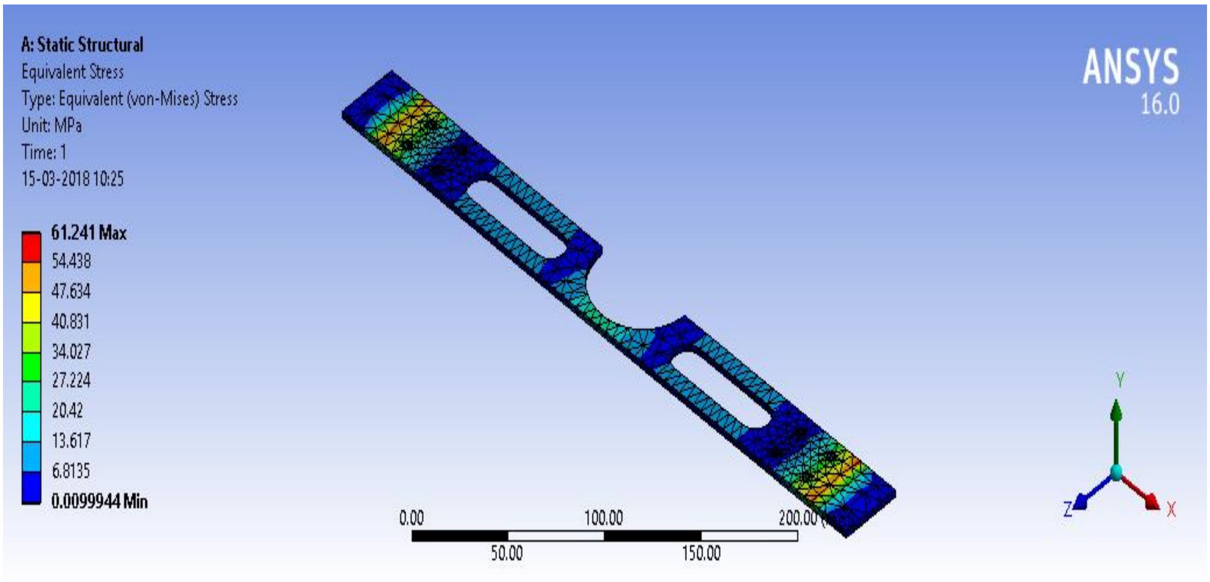
DESIGN:

The following iteration was selected because it was the design with minimum weight and optimum amount of strength. It is welded to the chassis members on both the sides to provide a rigid support. The Plummer blocks are bolted to the baseplate through the holes provided on it, and the whole weight of the assembly will act at the bolting points of Plummer to base plate.

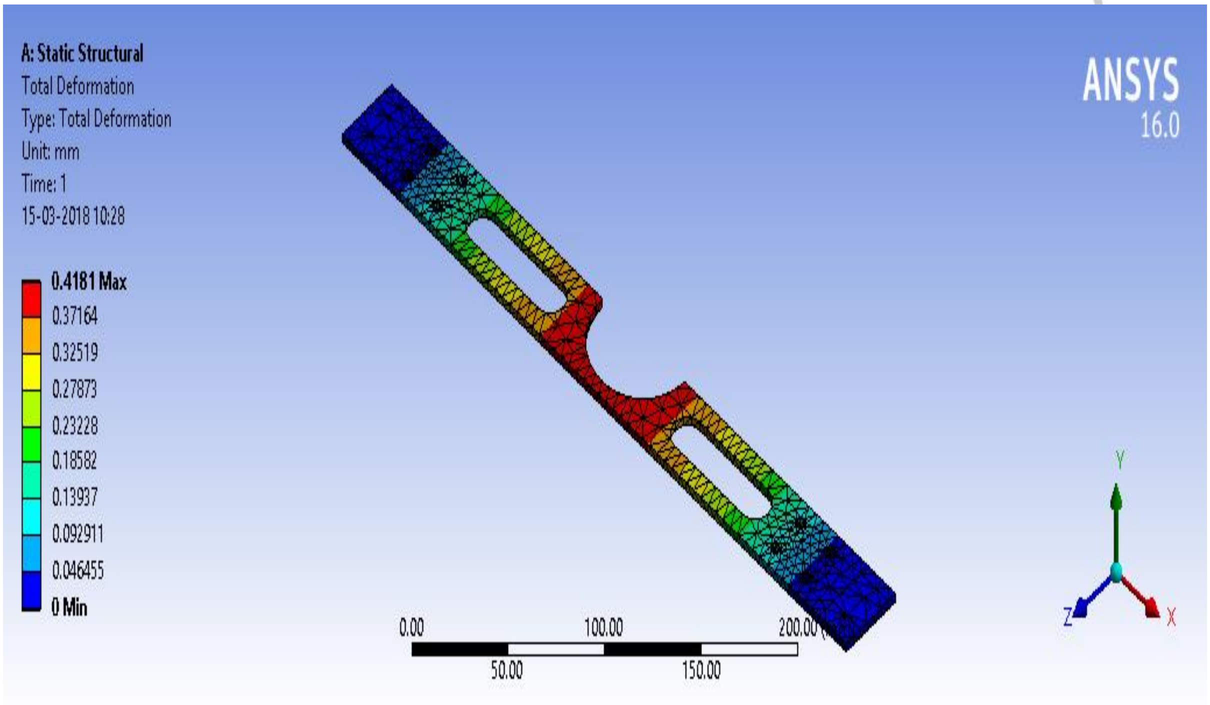
The base plate of the previous year was overdesigned and hence weight reduction was done in this year's design with an approximate weight of 227.1 grams which reduces almost 10 % weight than that of previous year's design

ANALYSIS:

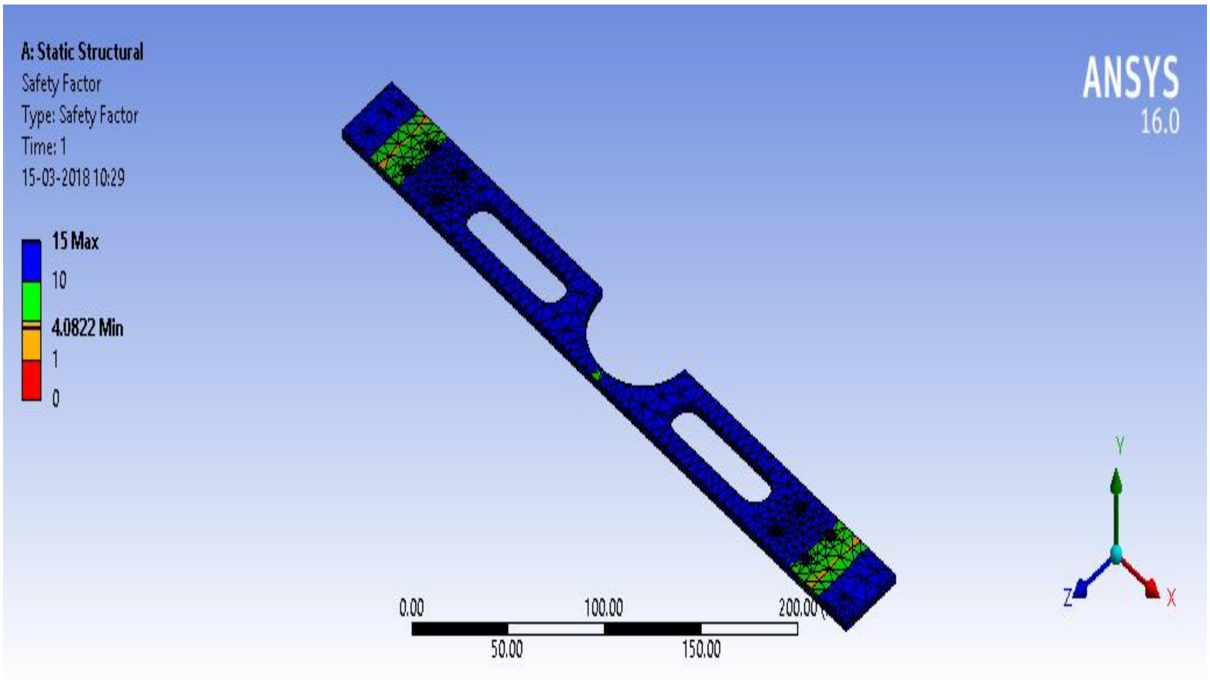
1. Equivalent stress:



2. Total deformation:



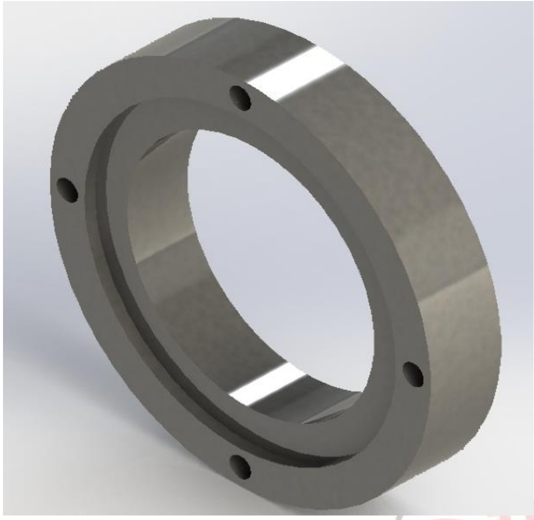
3. Factor of Safety:



MANUFACTURING:

A M.S plate of 372*40*3 mm was taken as the raw material keeping in mind the maximum dimensions of base plate and was manufactured by laser cutting it. Four holes of size 4mm were drilled symmetrically on both ends so that it can accommodate Plummer blocks which were being welded to the Rack housing holding the entire lower assembly.

7.2 Button:



Concept:

This Button is built to prevent the pinion bearing from getting outside the rack housing.

Design:

The Button is made up of material SS 304. It is made circular similar to the size of Rack housing of diameter 54mm. A step section is provided at the center to resist the pinion bearing to come out.

Manufacturing:

1. Turning
2. Jig Boring

The process was carried out in two stages:

- The purchased material was turned on lathe according to the designed dimensions having total length of 5mm and the step section of 1.5mm was provided in the same.
- Later the boring was done for 4 holes at the PCD of 49mm along with the rack housing.

7.3 Rack And Pinion Assembly:

Concept:

- A **rack and pinion** is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion.
- A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move relative to the pinion, thereby translating the rotational motion of the pinion into linear motion.

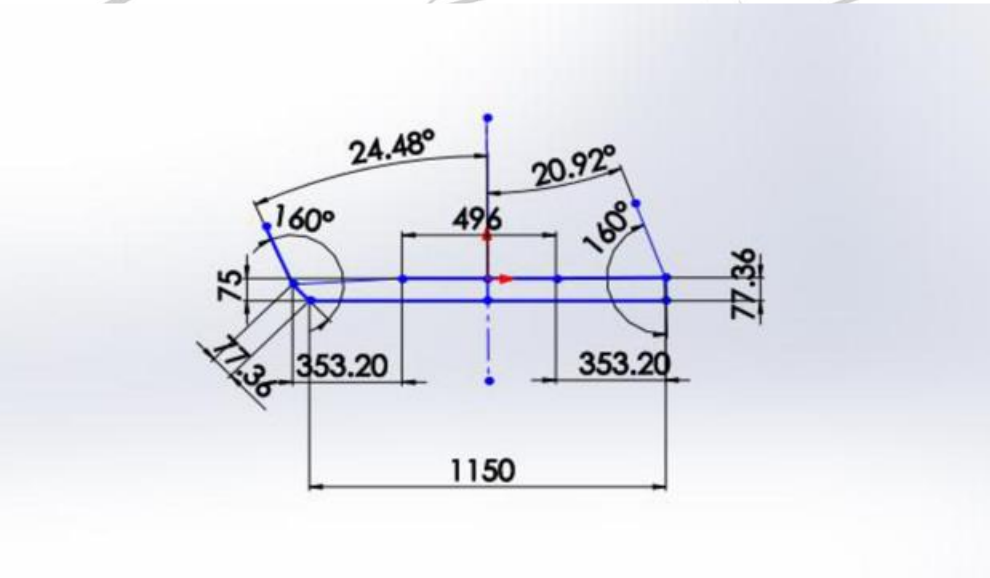
Rack and Pinion Geometry-

The main objective of this year's design was to increase the rack travel. This was obtained by increasing the c-factor which in turn increased the pinion diameter.

The length was decided so as to eliminate bump steer.

This is a highly approximate 2D representation of the geometry to determine the approximate c-factor of the pinion and to decide rack travel.

Iteration 1:



The rack travel was 28 on either side, and the steering angles obtained for that were 24.48 and 20.92 for inner and outer wheels respectively.

Steering wheel movement from lock to lock was taken to be 165˚. For this condition the c-factor was found to be 122.5mm/rev

Steering wheel rotation=Pinion Rotation

Now, steering wheel movement for max wheel movement=82.25 and that corresponds to travel of 28mm.

Therefore C-Factor= (28*360)/82.25=122.5

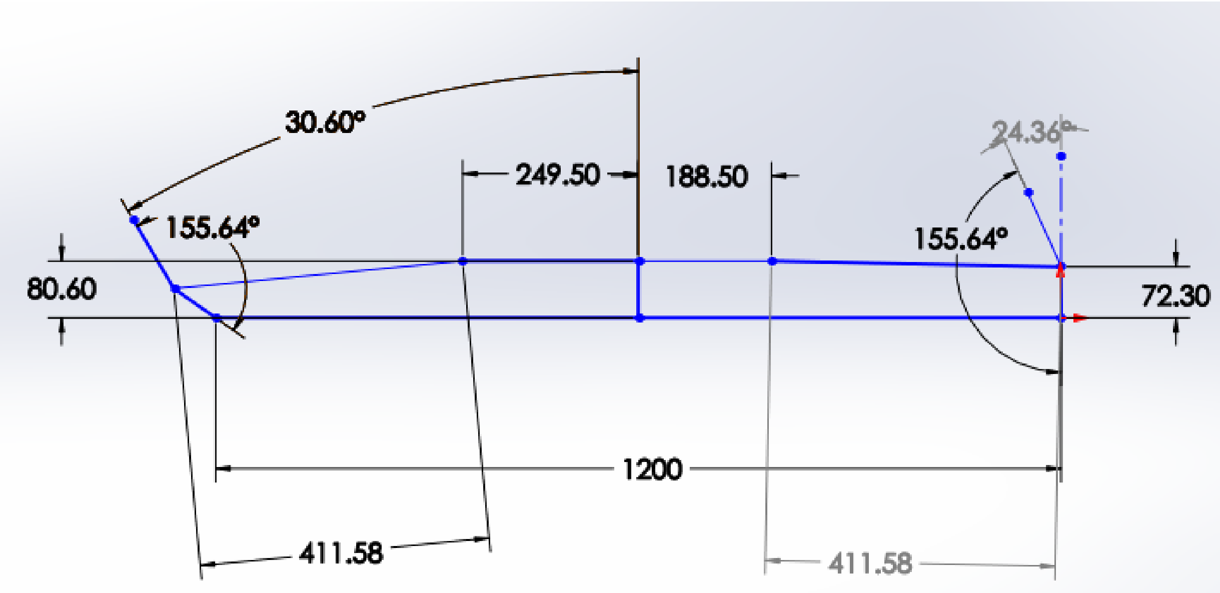
C-Factor=3.14*d, where d is diameter of pinion

Solving,

d =39mm.

Iteration 2:

A slight increase in C-Factor with a increase in the rack travel provided a proper design.



The rack travel was 31mm on either side, and the steering angles obtained for that were 24.36 and 30.60 for inner and outer wheels respectively.

Steering wheel movement from lock to lock was taken to be 180˚. For this condition the c-factor was found to be 124mm/rev

Calculations:

Steering wheel rotation=Pinion Rotation

Now, steering wheel movement for max wheel movement=90 and that corresponds to travel of 31mm.

Therefore C-Factor= (31*360)/90=124

C-Factor=3.14*d, where d is diameter of pinion

Solving,

d =39.5 mm.

Teeth Interference:

To avoid interference on the rack, minimum no. of teeth on the pinion is decided:

$t = 2AR/\sin^2(\Phi)$

Where, t- no of teeth

AR- fraction to be multiplied with module to get addendum Φ-
Pressure angle

AR= 1.25 [Design Data Book PSG 8.2]

$t = 2*1.25/\sin^2(20) = 21.37$

Required PCD

C factor= 124

PCD= C factor/π= 39.5mm

Case 1:

Teeth= 25
m=39.5/25=1.58

Closest module, m=1.6

PCD= 1.6*22= 40mm

C factor= 40*π= 125.67

Case 2:

Teeth= 26
m=39.5/26=1.52

Closest module,
m=1.5

PCD= 1.5*26= 39mm

C factor= 39*π= 122.5

This value is closest to the required C factor.

Teeth= 26, module= 1.5

Checking Strength

σb> (i+1)*[Mt]/ (a*m*b*y)i=0
for RnP

a= center distance= 16.25mm
m=1.5mm

b= 12*m= 18mm

y=0.154-0.912/Z = 0.1189 [Design Data Book PSG 8.50]
[Mt] is obtained from the aligning torque diagrams

Force on Rack,

FR = (MFR + MFL + FYFR*KinTr + FYFL*KinTr)/ StArm

= (40.8 + 3.2 + 1339.48*33.7/1000 + 230.17*33.7/1000)/.07736
= 1252.55 N
[Mt] = 1252.55*19.5/1000 = 24.42 Nm

RnP Calculation (Cont.)

σb> (i+1)*[Mt]/ (a*m*b*y) = 24429/ (19.5*1.5*15*0.1189) = 468.28N/mm²

The rack and pinion are hardened to 35 HRC. Assuming 35 HRC, which converts to 389 HB hardness.

σb for EN24 normalized is approximately 1000N/mm² for 302 HB.

Hence the design is safe.

RACK

Design**:**

The rack for DJSR04 is designed in a much similar way than DJSR03.The man objective of it was to maintain the structural rigidity of it even though reduction in weight is necessary. It is made in 2 parts, out of which one is the rack base made out of Al7075 and other is the rack teeth which is made up of EN24. Both the parts would be fastened together with the help of 2 M4 bolts so that they don't have any kind of play nor do they move relative to each other.

The main reason for this kind of design is that maximum stress concentration occurs near the teeth. The Rack Base was made circular this year which resulted in 13% weight reduction than last year's design.

The rack base weighs 280 grams.

Manufacturing:

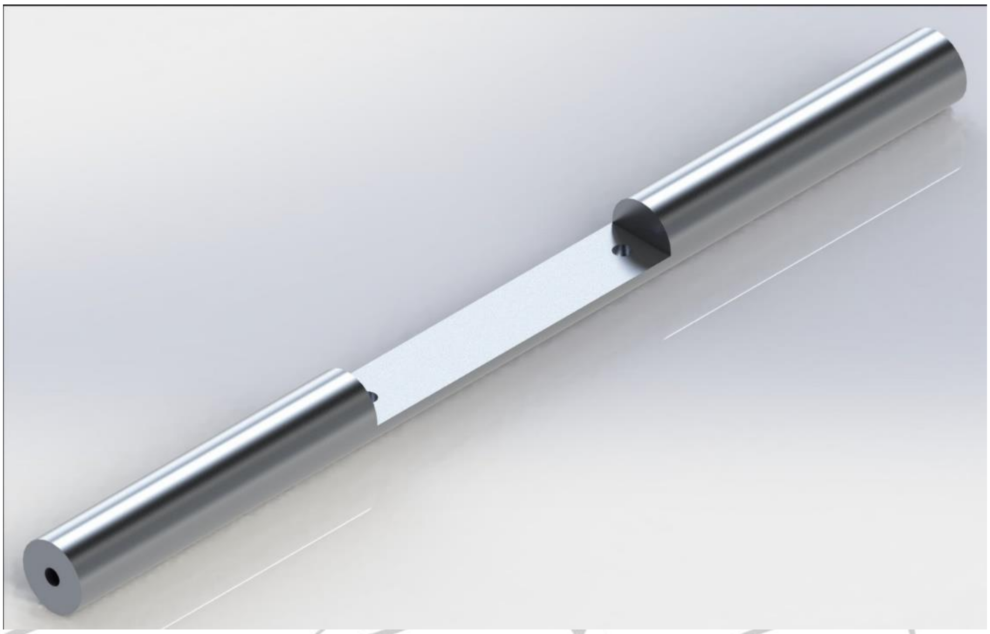
Rack

The rack was manufactured in two parts:

A. Rack Base
B. Rack Teeth.

A. Rack base

Aluminum 7075 was procured having dimensions 320*25mm circular rod



CONCEPT:

Rack Base holds the rack teeth with the help of 2 M4 bolts. The rack base is connected to clevis at its two ends. The rack base slides easily and effortlessly inside the rack housing.

DESIGN:

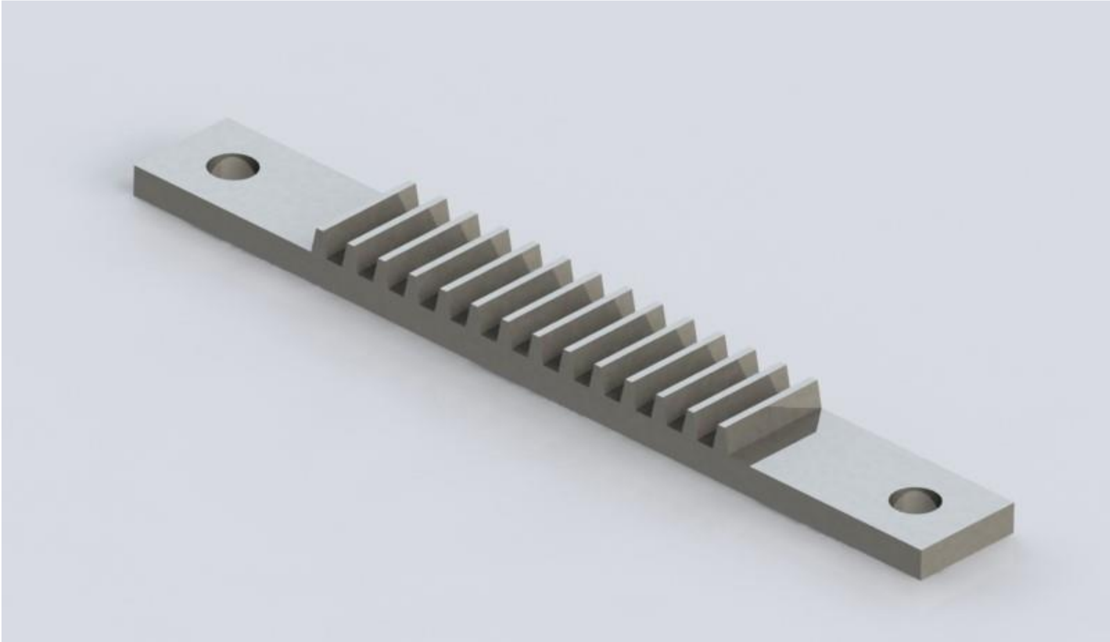
The rack base is made circular in shape with outside diameter of 24mm. last year the rack base was made rectangular due to the shape of rack housing. But this proved to be difficult in manufacturing. Hence this year the rack base is made circular for feasibility in manufacturing and for weight reduction.

MANUFACTURING:

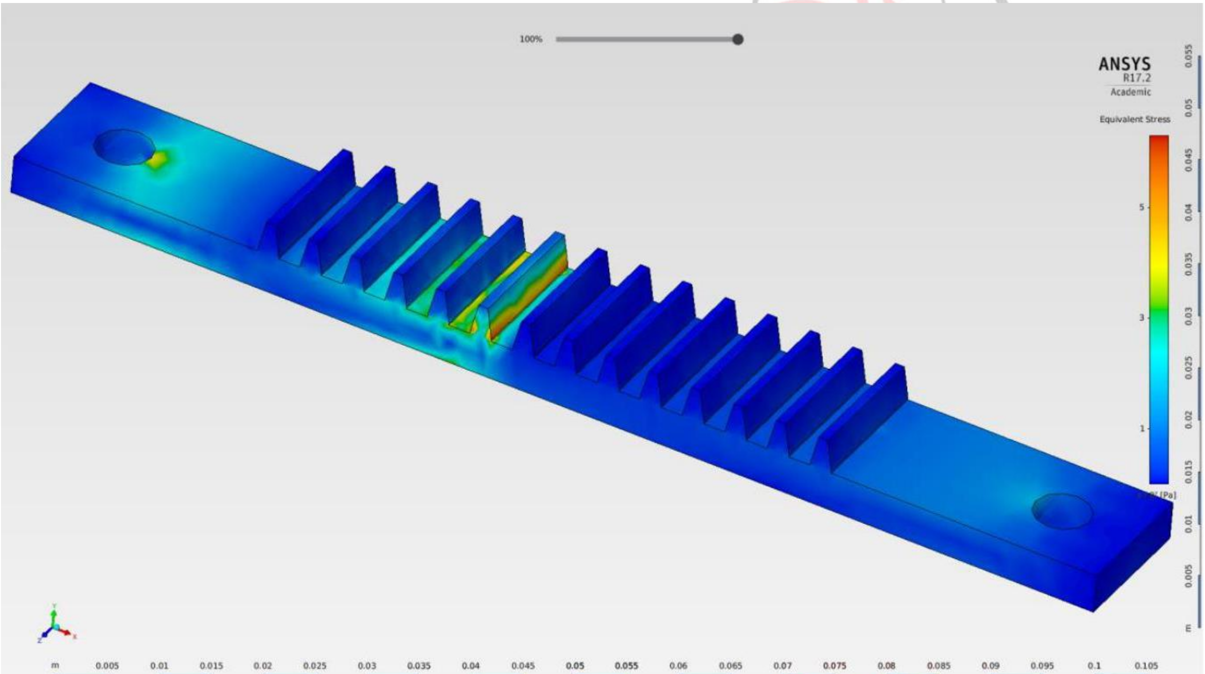
A billet of dimensions 26mm diameter and length 320mm was taken. The material chosen was Al 7075.

1. Initially the rack base was turned on conventional lathe to the desired diameter of 24mm.
2. The middle slot of 120mm was made on conventional milling.
3. Two holes of diameter 6mm was drilled in this slot for bolting of Rack teeth.
4. At each end Drilling was done for Clevis which would accommodate M8 bolts.

C. Rack teeth



Analysis:



The material was procured as a rectangular block having dimensions 121mm*16mm*9mm.

Material:

EN24 was selected as pinion was already made of EN24. As both these parts will mesh together, it is necessary that both must be of the same material so as to prevent shearing.

Process used:

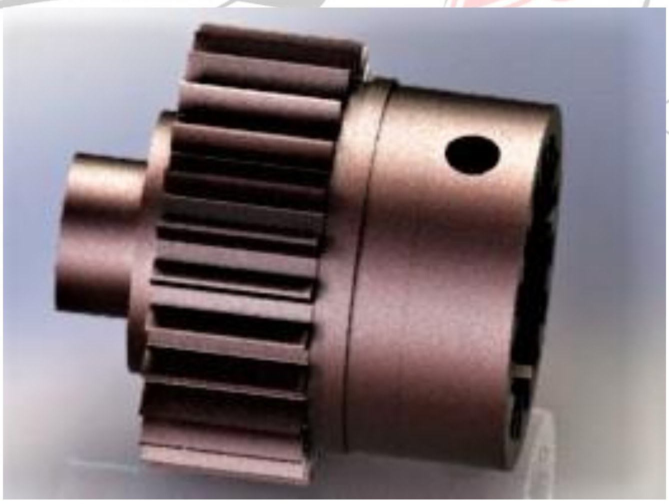
1. Milling
2. Drilling and tapping

Process setup:

The process was done in the following 3 setups:

- It was processed on milling machine using the indexing method.
- Teeth were produced using mill form cutter
- Holes were drilled on both sides for fastening it with rack base. The holes were further tapped. This part was hardened to enhance its strength properties.

PINION



Design:

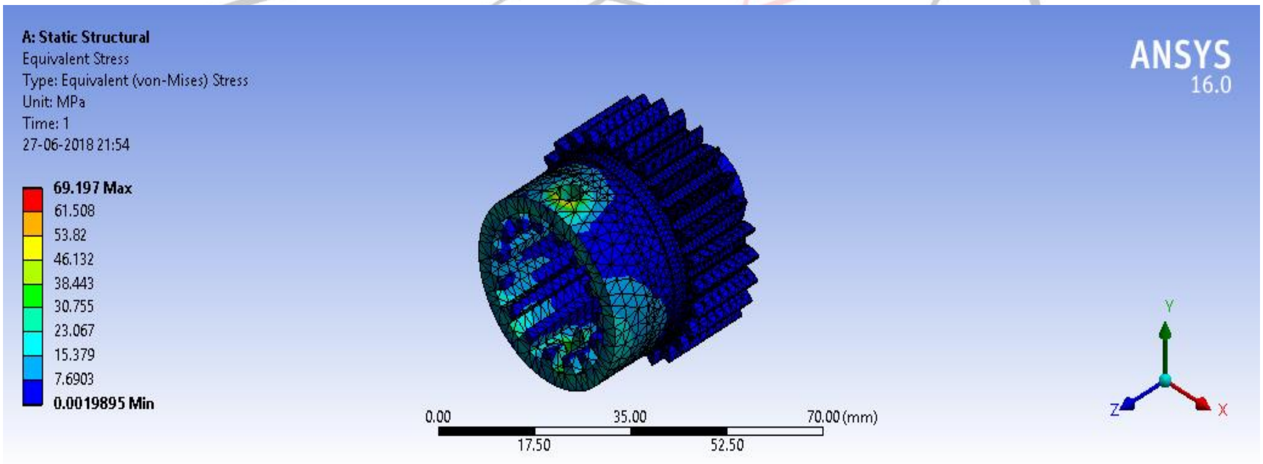
Earlier the pinion was bolted to the column with the help of nuts, bolts and saddle washers but this arrangement resulted in play due to which splines were machined on the inside of the pinion and outside of the column shaft which is slide fitted into the pinion and then they both are fastened with the help of grub key which reduced the overall play in the system to a great extent making it negligible.

The pinion was made out of EN24 as it is a crucial component. Two bearings are press fitted on both sides of the pinion to provide smooth rotational motion and to reduce the wear rate. Deep groove ball bearings having dimensions 15-24 and 35-44 are used foe smoother rotation of pinion.

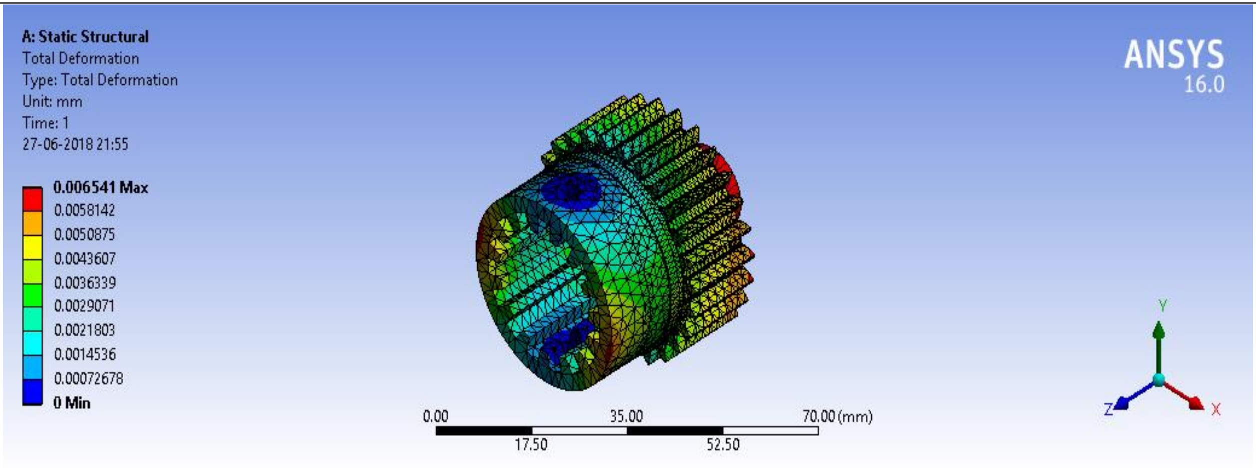
The pinion was hardened to 35 HRC so as to reduce the amount of wear caused due to high stress concentration at the teeth. It weighs around 200 grams.

Analysis :

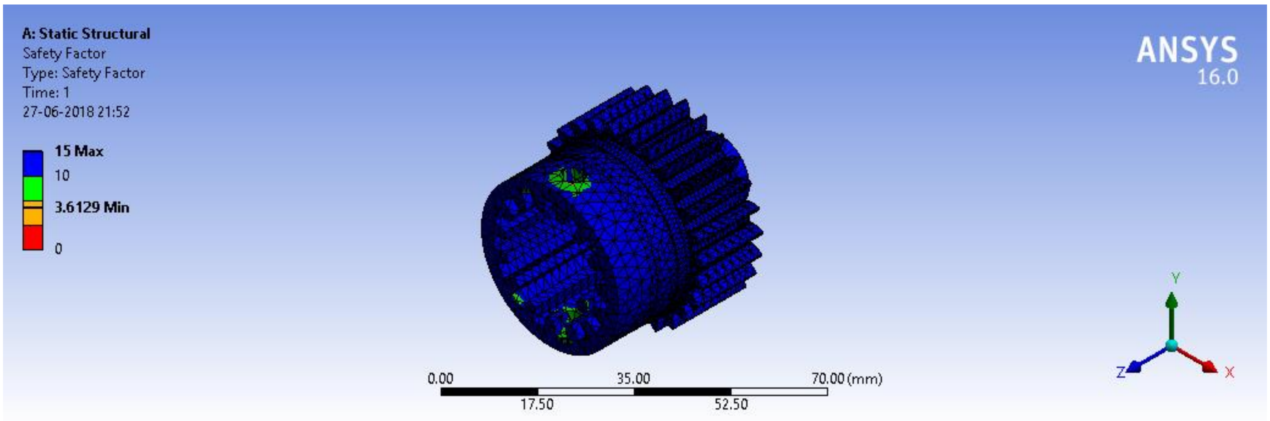
Stress Analysis :



Total deformation:



Factor of Safety:



Manufacturing:

A hollow material of EN24 was procured having outer diameter 45 mm and inner diameter 4mm. Length of the material being 45mm.

Process used:

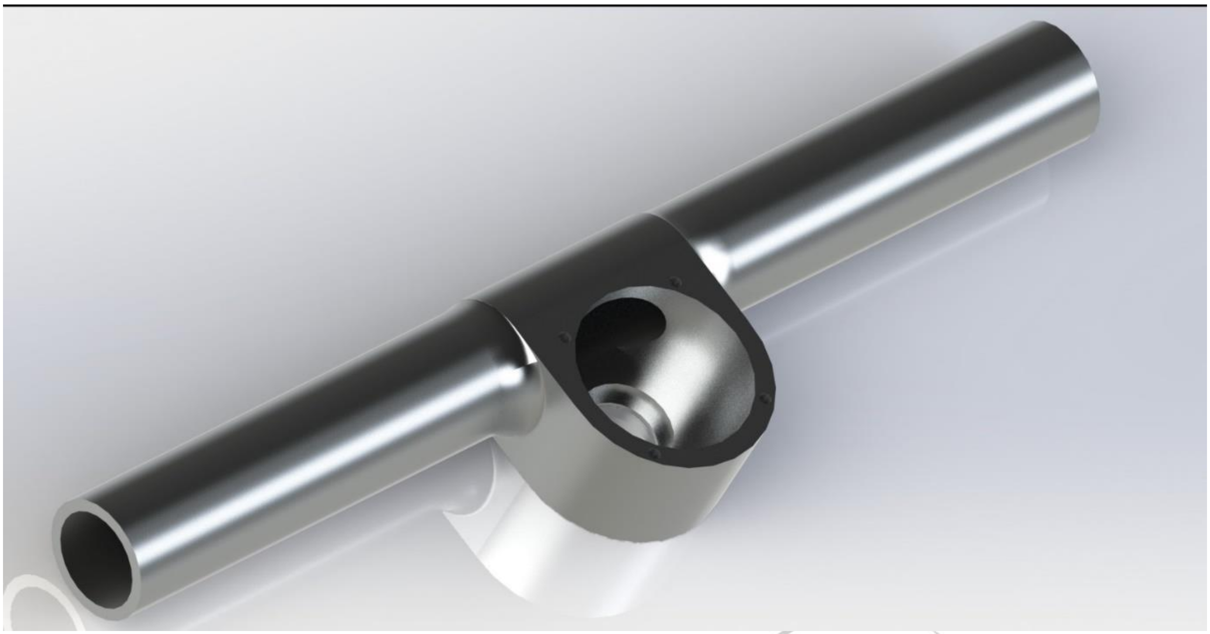
1. Turning
2. Milling
3. Gear hobbing
4. Drilling

The process was carried out in 4 stages:

- Firstly the diameters were made to size by proper turning operation and tapering operation was performed using the same tool turning center. The coolant used was cutting oil.
- The splines were created on the inner periphery of it using the milling process using a broaching tool.
- Teeth were cut on the outer periphery using the gear hobbing process and mill form cutter.
- A hole was drilled and tapped up to a length of 15mm for insertion of grub key.

:

7.4 Housing Assembly



CONCEPT:

The Rack Housing holds the Rack base and the Rack teeth. The housing is made circular such that the rack housing slides easily in it.

DESIGN:

The Rack Housing is made circular for its easy manufacturing and smooth sliding of the rack base inside it. The housing is provided a stepped hole at the Centre for proper fitting of the pinion in it with bearings. The material chosen was Al6061 for its light weight and high durability properties. Also there were 4 holes drilled at a PCD of 49 for the button to get bolted. It was further anodized to maintain its strength and prevent corrosion.

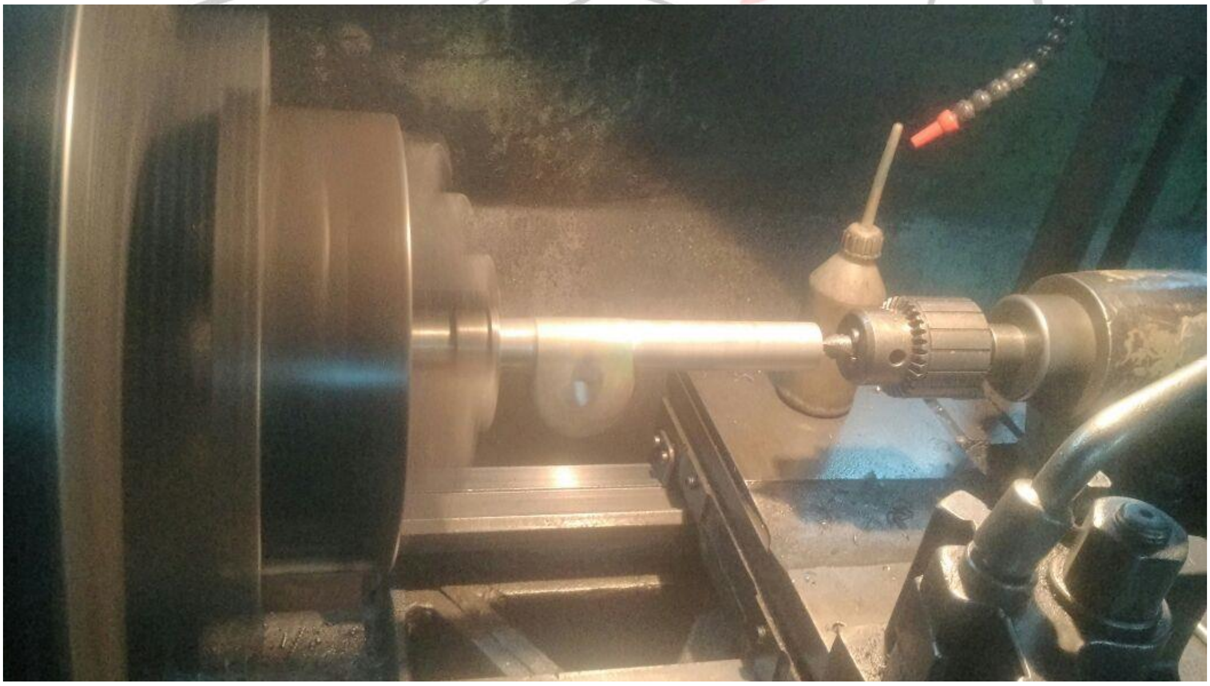
The previous car contained square rack base. However it was difficult for manufacturing. Hence, this year circular rack base was chosen for feasibility in manufacturing.

Its weight is approximately equal to 275gm.

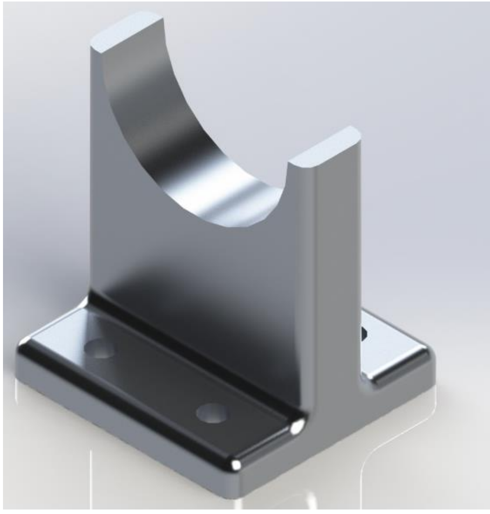
MANUFACTURING:

A raw material block of dimensions 65x32x270 was taken. The material chosen was AL 6061.

1. Initially CNC Milling was performed to create the outermost profile.
2. Then the drill for the pinion was made and checked for perfect fit.
3. Then a through hole was drilled for the rack base to slide fit of diameter approximately of 30mm.



PLUMMER BLOCK



CONCEPT:

Plummer blocks were used to rigidly support the rack housing. Plummers were used so as to provide proper rigidity to the assembly. Proper dimensions were decided based on the coordinates of the rack. The dimensions of curvature slot were decided based on the outer dimensions of rack housing. It is bolted to the base plate with the help of four bolts on each Plummer and two Plummers on the extreme sides of the rack housing.

DESIGN:

The Plummer consists of two pieces and supports the rack and pinion housing. The thickness is 10mm.It weighs around 42 grams each and is made up of Al 6061.

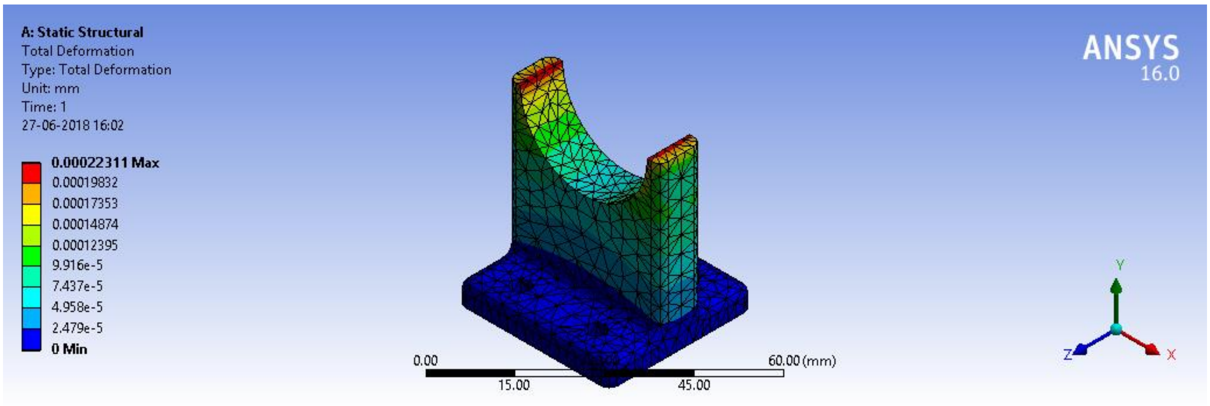
MANUFACTURING:

A raw material of 50x50x50 mm was taken.

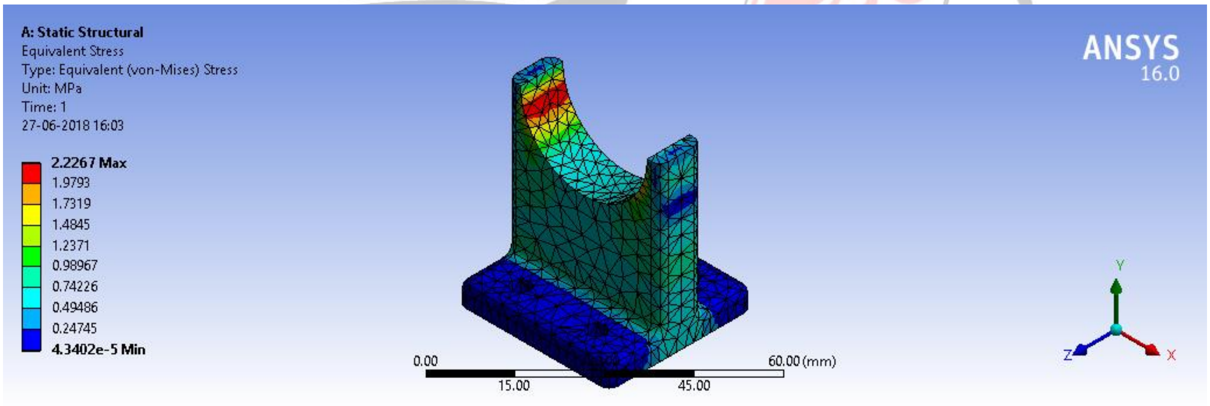
1. CNC Milling was performed initially to create the profile where the rack housing will rest of diameter 30mm
2. The extra material was then removed by milling to create the exact shape.
3. 4 holes of diameter 4mm were then drilled to bolt the Plummer to the base plate on the chassis.

ANALYSIS:

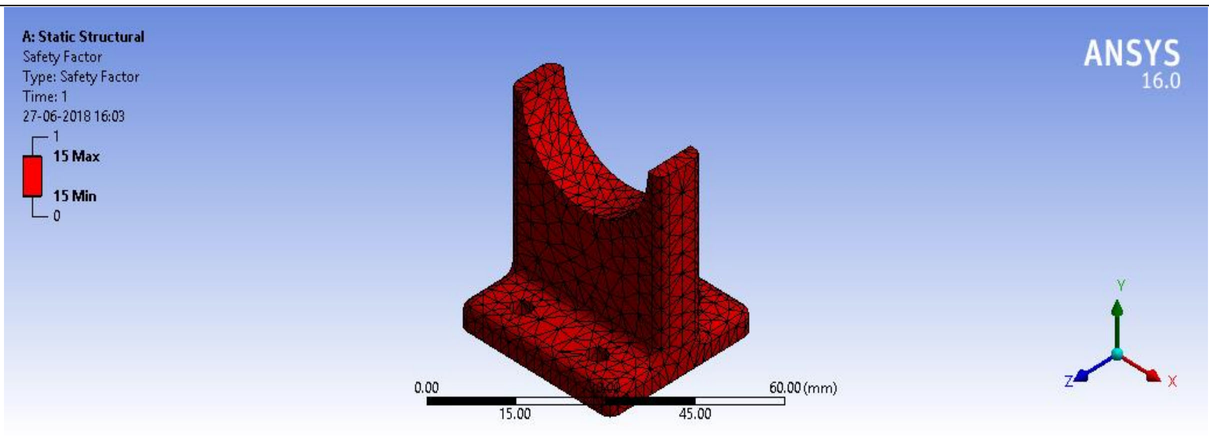
Total Deformation



Equivalent Stress



Factor of Safety


A: Static Structural
Safety Factor
Type: Safety Factor
Time: 1
27-06-2018 16:03
1
15 Max
15 Min
0
ANSYS
16.0
0.00
15.00
45.00
60.00 (mm)
Y
Z
X

HOUSING ASSEMBLY

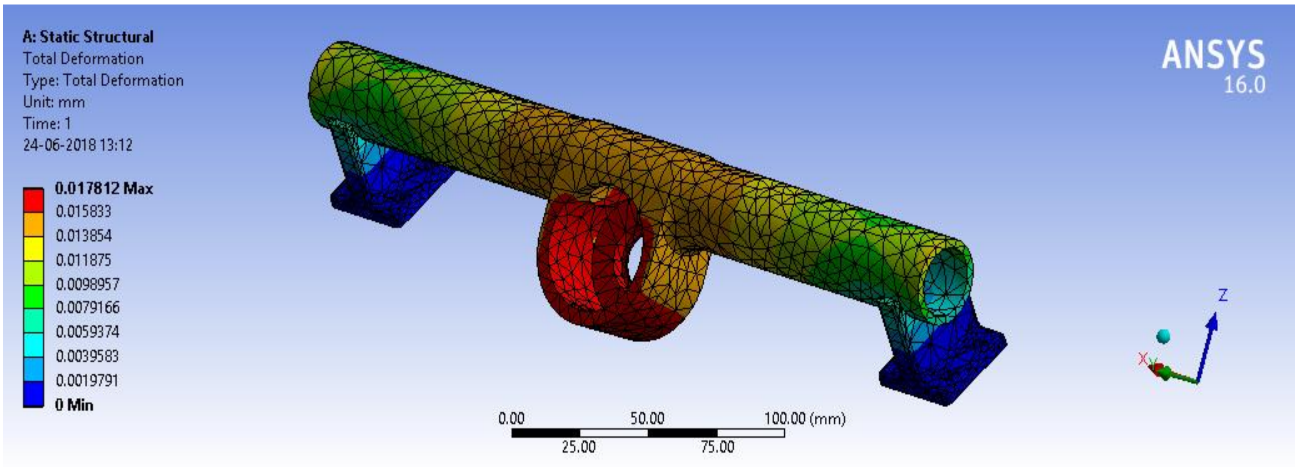
The Rack Housing is welded to Plummers to maintain stiffness. The Plummers are then bolted to the base plate on the chassis.

Last year a separate bush was used for positive stopping. In this year's design we have increased the diameter of the clevis which will help in positive stopping. This gave us a reduction in weight. Also the final housing assembly was welded i.e. housing and Plummer blocks were welded by taking proper alignment and fixtures.

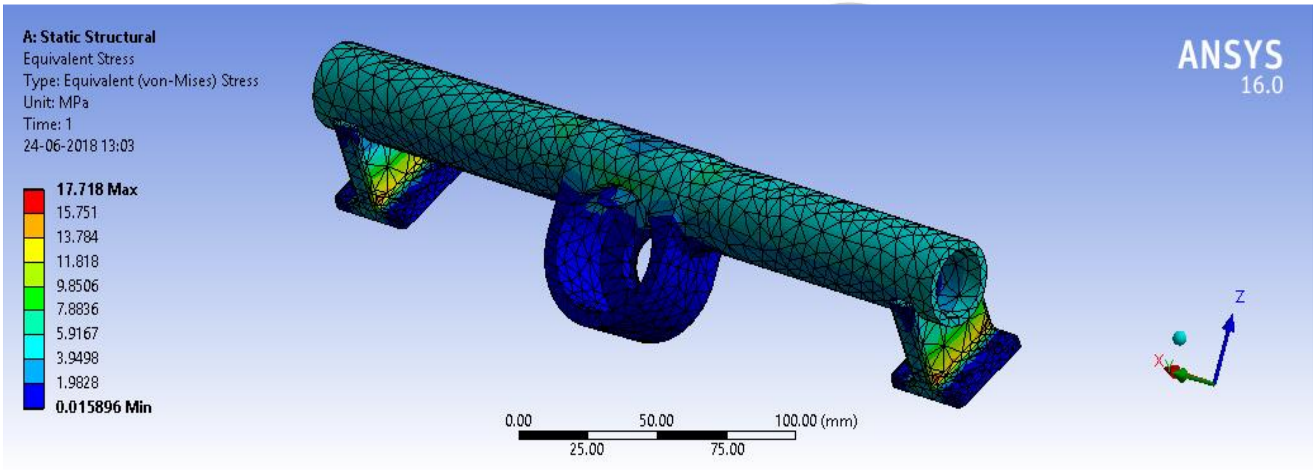
The total weight of the assembly is approximately equal to 1450gms.

ANALYSIS:

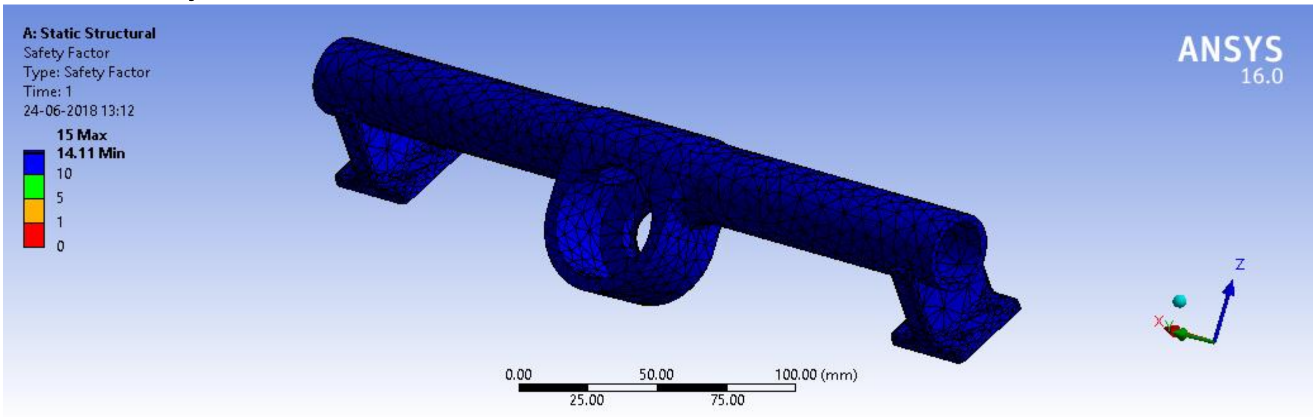
Total deformation:



Equivalent stress:



Factor of safety:



7.5 CLEVIS:

Concept:

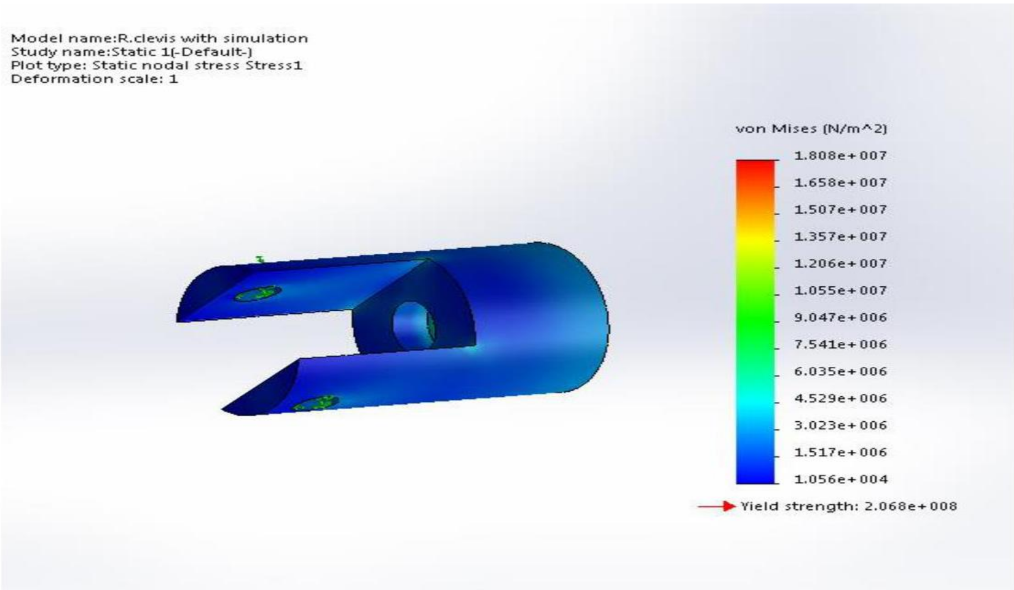
Clevis connects the rack to the tie rods. It is bolted with the rack base at each of its ends in such a way that it has rotational degree of freedom about its axis. It also acts as medium for positive stopping.

Design:

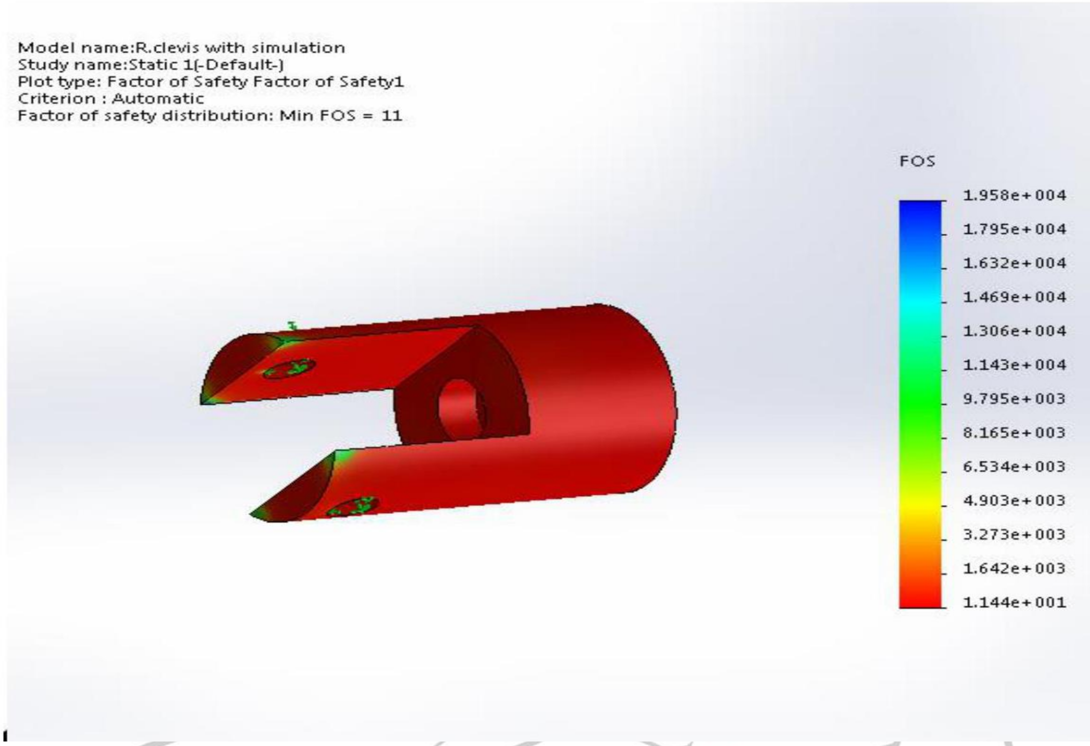
The main aim while designing the clevis was to reduce weight and at the same time maintaining its strength and purpose. The Diameter of the clevis is larger than the Rack base and it is bolted to it using a tab washer which makes it a positive stopping at exactly 31 mm when it hits the Rack housing on either side. It weighs 103.81 grams.

Analysis:

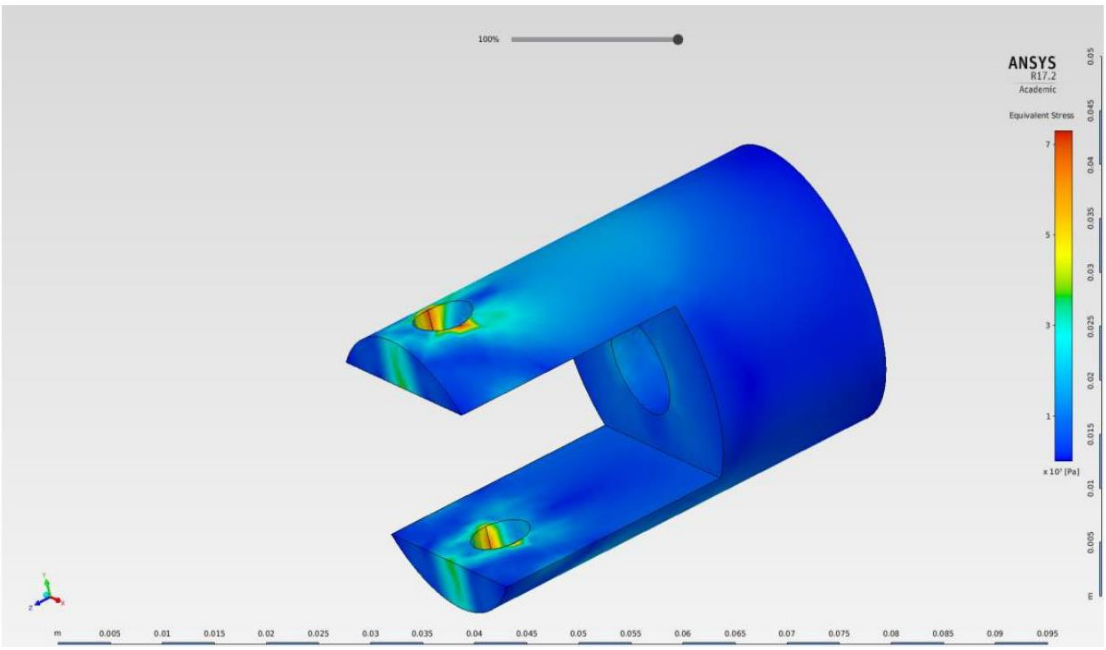
Equivalent Stress:



Factor of Safety:



Deformation:



Manufacturing:

A billet of SS with outer diameter 28 mm and length 90 was procured for both the clevises together keeping in mind the maximum dimensions of clevis and machining allowance.

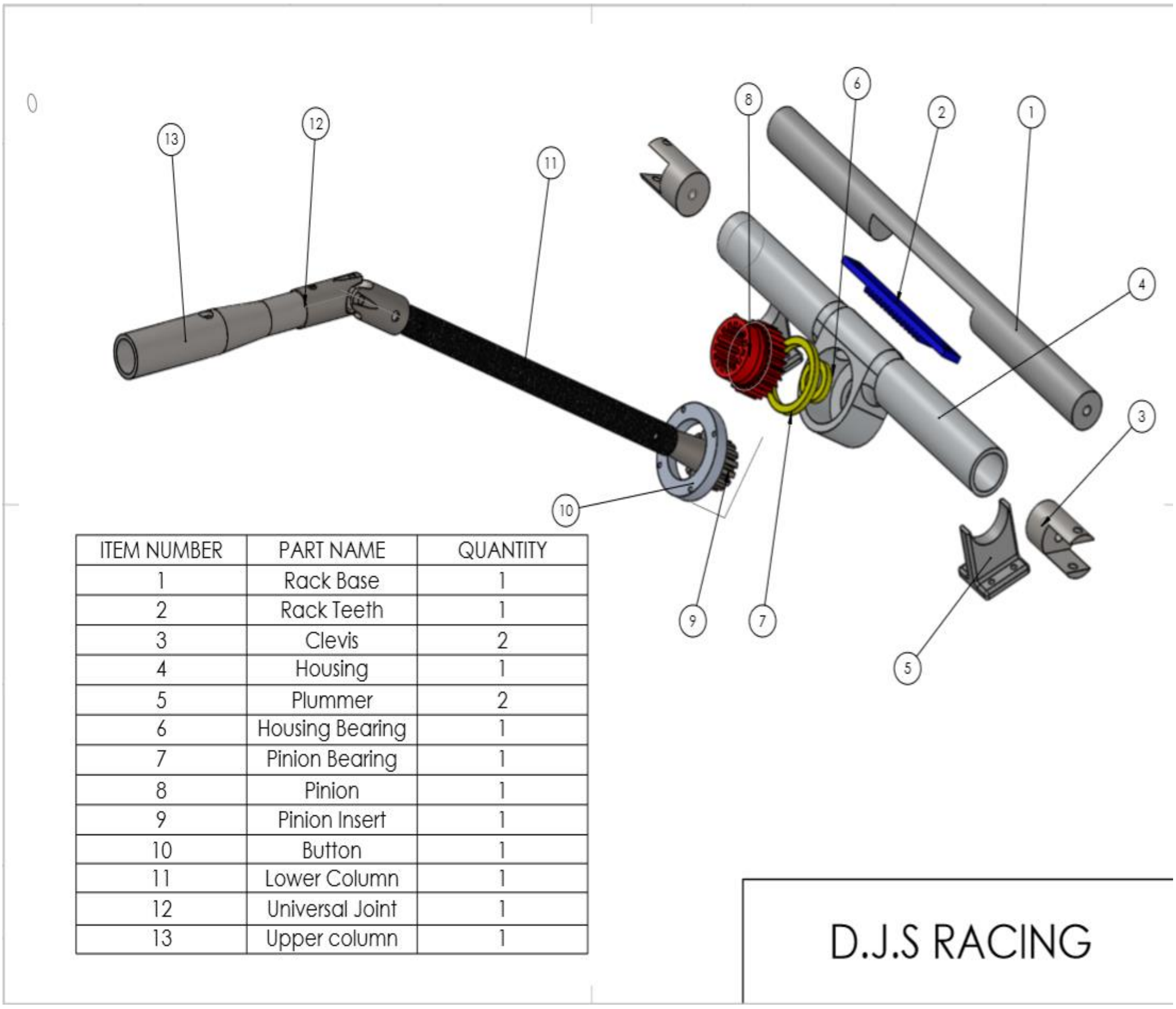
Processes used:

1. Turning
2. Drilling
3. Conventional Milling

The manufacturing of both the clevises was done in further steps each:

- Turning operation was performed on the billet using a tip tool to reduce its diameter to the maximum outer diameter of the clevis which is 27 mm and cutting oil was used as a lubricant from time to time to get a proper surface finish and to absorb all the heat generated during the process.
- Drilling operation was performed using a drill to produce a through and through hole of diameter 6mm.
- Conventional Milling operation was performed so as to get the desired slot.

Lower Assembly And Column Assembly:



ITEM NUMBER	PART NAME	QUANTITY
1	Rack Base	1
2	Rack Teeth	1
3	Clevis	2
4	Housing	1
5	Plummer	2
6	Housing Bearing	1
7	Pinion Bearing	1
8	Pinion	1
9	Pinion Insert	1
10	Button	1
11	Lower Column	1
12	Universal Joint	1
13	Upper column	1

8. Tie Rods:

Concept:

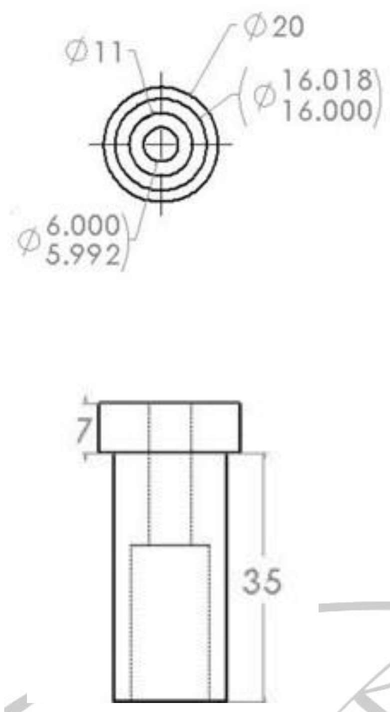
Tie rod is a linkage in steering mechanism which connects the upright with the rack and helps in transmitting the motion from rack to the wheels.

Design:

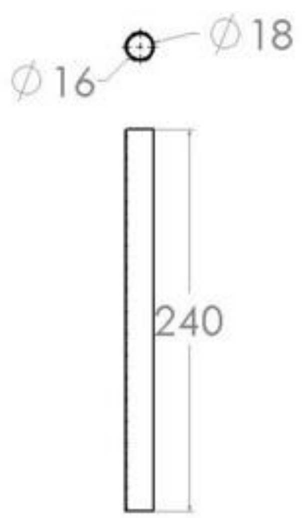
Previously the tie rods were made of MS which had considerable amount of weight but then we decided to make the tie rods from CF with proper inserts so as to achieve an optimum design with proper weight reduction. The dimensions of the CF tie rod were decided based on the amount of force acting on the tie rod and hence approximate dimensions were selected and the testing was done so as to prove our selection was proper. Last year's Tie rod weighs around 200gms with rod ends whereas this year's weight is around 130 grams with inserts and rod ends hence obtaining a weight reduction of 35%.

Tie Rod Inserts:

Tie Rod inserts DWG:



CF Tie rod DWG:



CF Tie rod with inserts and spherical rod ends:

Manufacturing:

Process used:

Hand layup process was used for manufacturing of tubes. .200gsm, 3k fabric of twill type was used so as to obtain adequate strength.

Later the CF rods were bonded with the inserts using Loctite 120hp

Testing:

The force on the rack as calculated before was found to be 1252.55N and from the testing data we got to know that the rod failed under a compressive stress of 12.64Kn and thus this design was selected keeping as the FOS obtained was around 10.

Testing Data:

Tie Rod 1 18-16

210mm 25.79kN

Tension

Tie Rod 2 18-16

240mm 12.64kN

Compression

Before:

After:

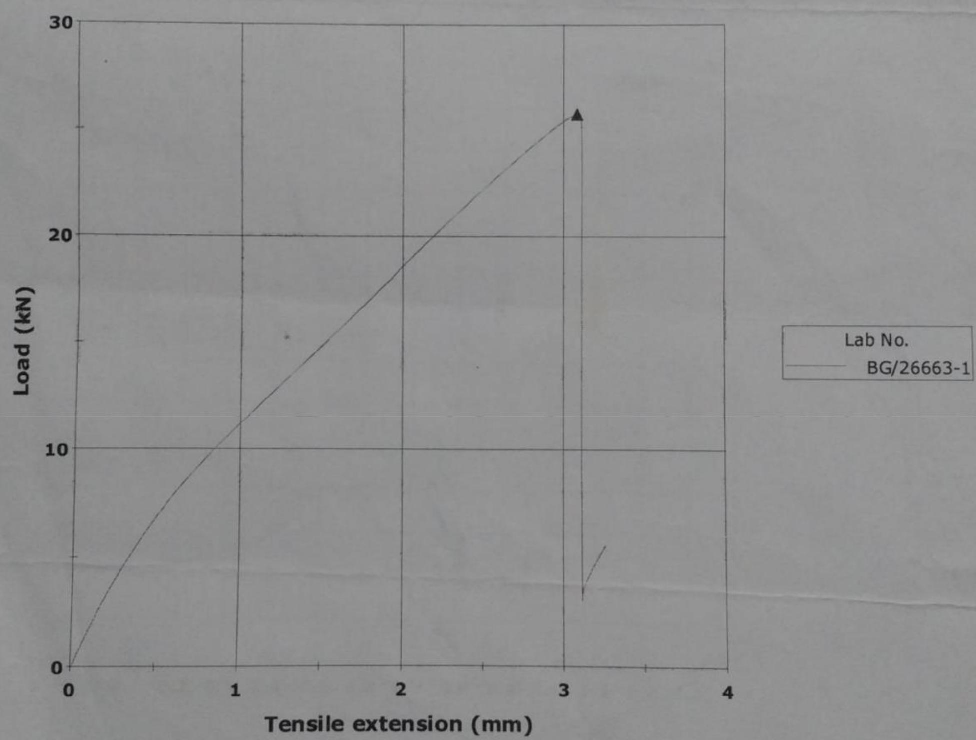
Testing graphs:

Exova METALLURGICAL SERVICES

Metallurgical Services Pvt. Ltd.
(An Exova Group company)

Party Name	DJS RACING
Witness By	**********
Test Date	18/10/2016
Temperature	ROOM TEMP

Tensile Test



Lab No.	ID NO.	O.D (mm)	Thk (mm)	Area (mm^2)	Maximum Load (kN)
BG/26663-1	TIE RODS 1	9.50	0.72	19.86	25.79

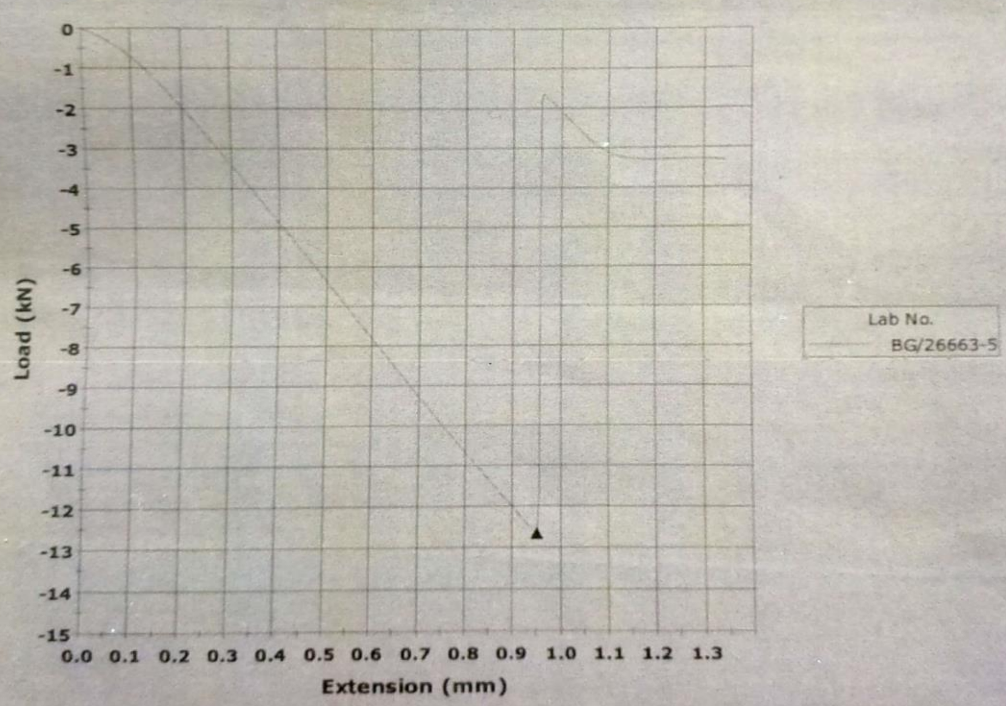
Tested By Metallurgical Services P. LTD.

Exova METALLURGICAL SERVICES

Metallurgical Services Pvt. Ltd.
(An Exova Group company)

Party Name	DJS RACING
Witness By	*****
Test Date	18/10/2016
Temperature	ROOM TEMP

Compresive Test



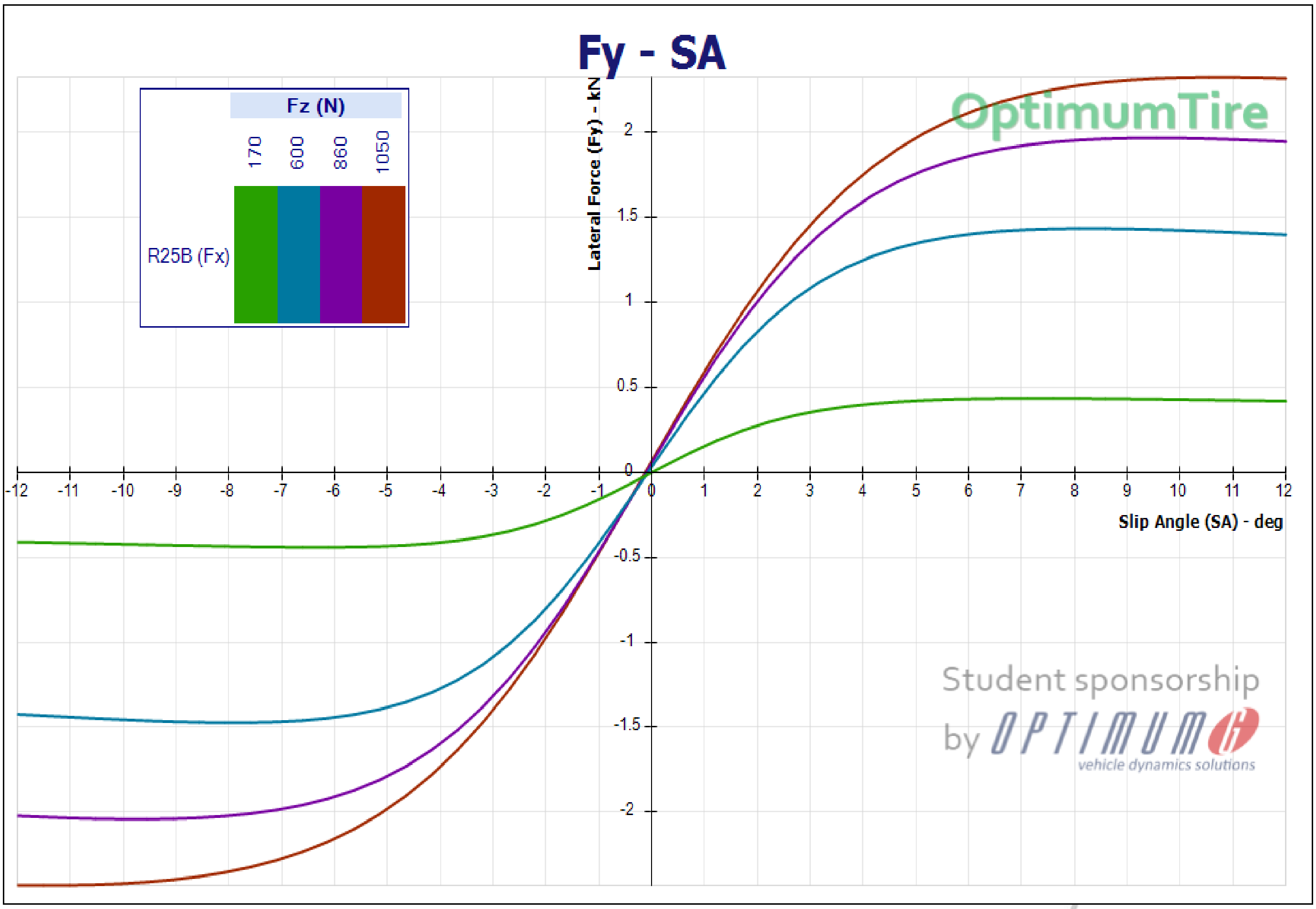
Lab No.	ID NO.	O.D (mm)	Thk (mm)	Area (mm^2)	Minimum Load (kN)
BG/26663-5	Tie Rods 2	9.50	0.72	19.86	-12.64

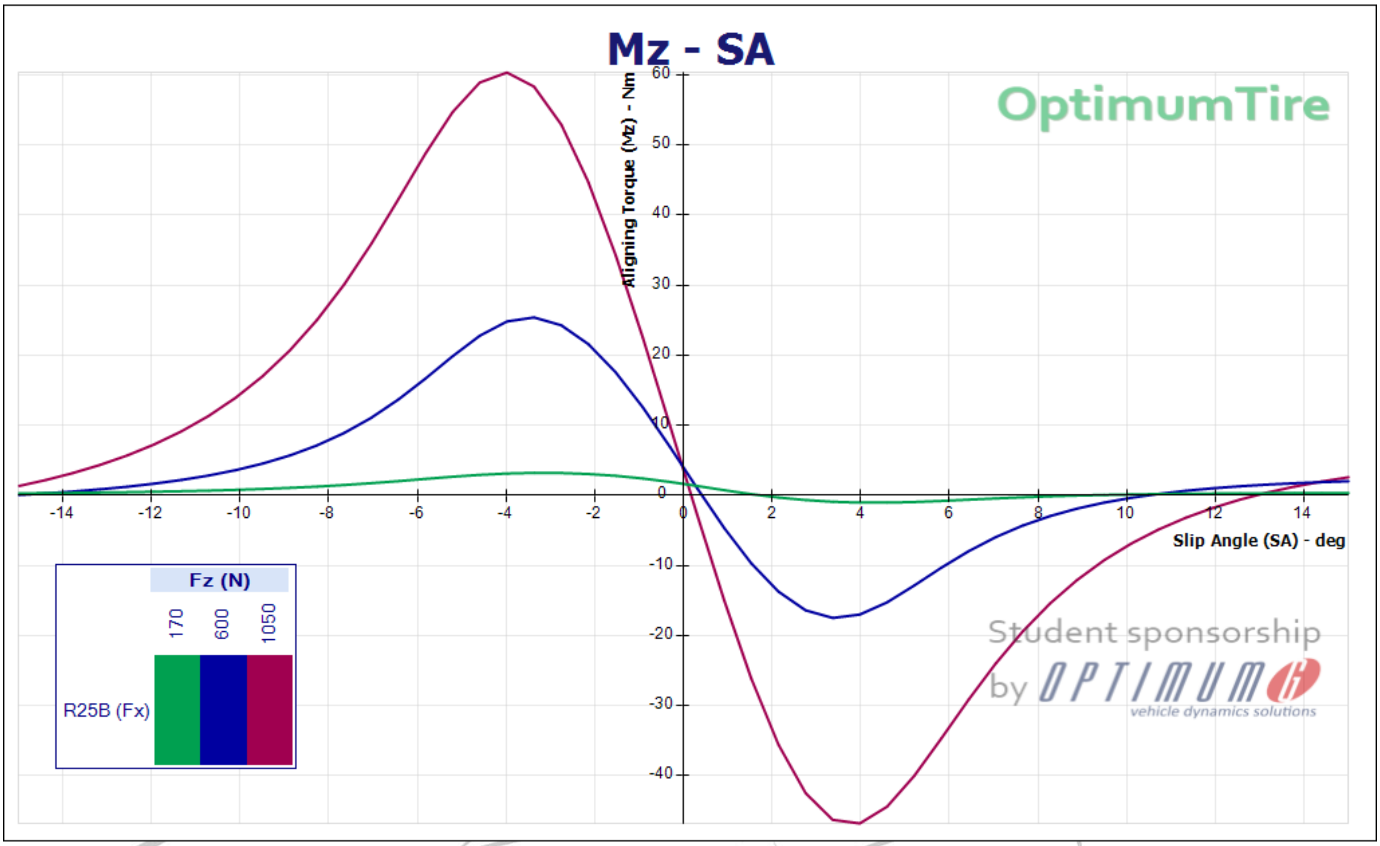
Tested By Metallurgical Services P. LTD.

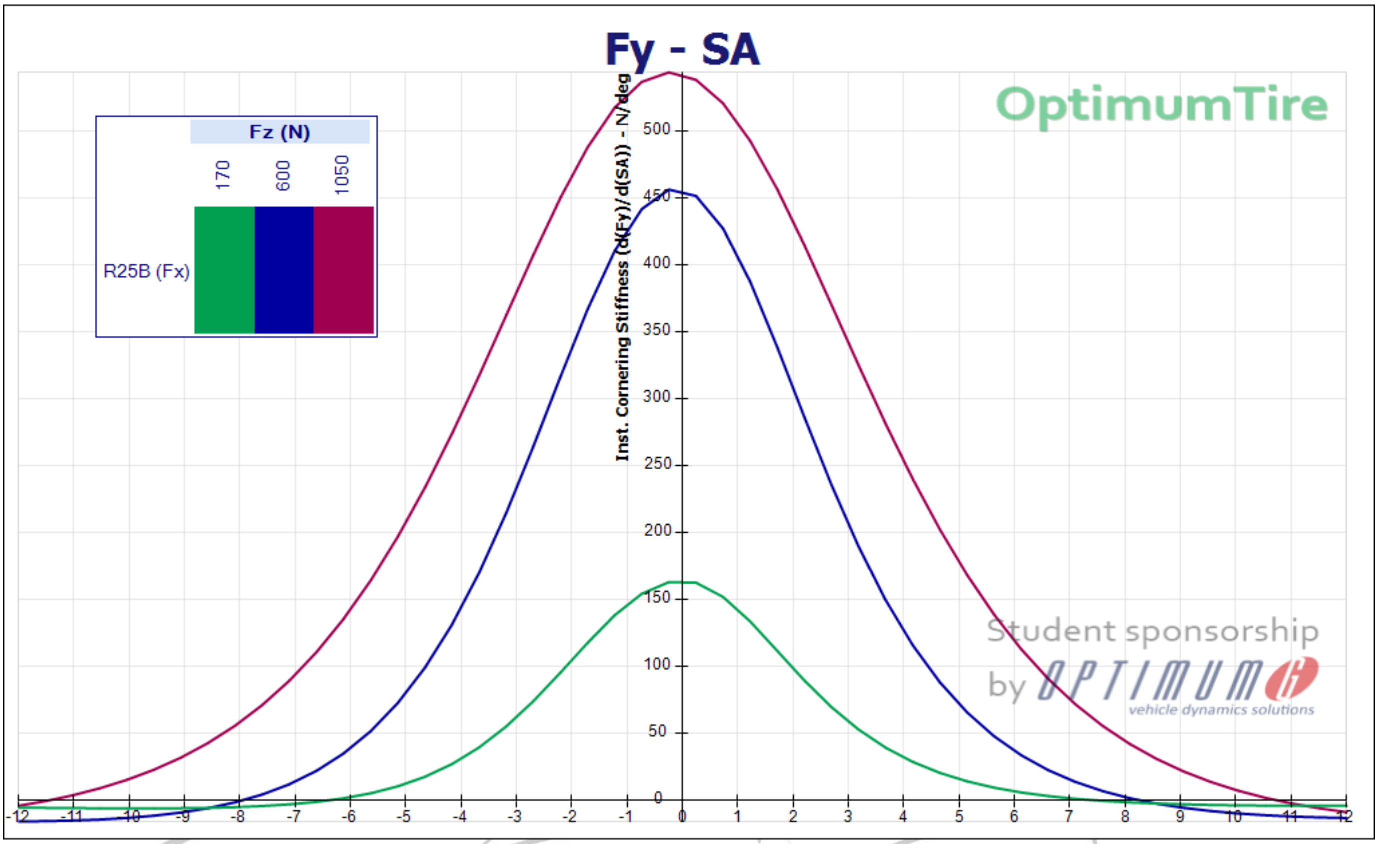
9. Tire Data:

Model Type		
MF 5.2		
Coordinate System		
Adapted SAE, Default		
General		
	Fz0	1556.878
	R0	0.4572
	V0	11.176
Pure Lateral		
	pCy1	1.518137
	pDy1	2.084329
	pDy2	-0.54937
	pDy3	7.239342
	pEy1	0.016295
	pEy2	0.040121
	pEy3	10.30678
	pEy4	-509.063
	pKy1	20.03801
	pKy2	0.709046
	pKy3	1.129397
	pHy1	0.005941
	pHy2	0.00651
	pHy3	0.058796
	pVy1	-0.07121
	pVy2	-0.0651
	pVy3	1.69672
	pVy4	-0.11334
Pure Longitudinal		
	pCx1	0.684584
	pDx1	3.080158
	pDx2	-0.89182
	pDx3	10.249
	pEx1	0.453713
	pEx2	-0.33433
	pEx3	-0.61244
	pEx4	-0.5404
	pKx1	23.1801

	pKx2	0.454105
	pKx3	-0.46918
	pHx1	0.07051
	pHx2	0.093521
	pVx1	0.271556
	pVx2	0.124214
Aligning Torque		
	qBz1	-5.27591
	qBz2	0.864977
	qBz3	3.776961
	qBz4	-3.43072
	qBz5	3.391463
	qBz9	3.349389
	qBz10	-1.01978
	qCz1	1.066492
	qDz1	0.129198
	qDz2	0.015239
	qDz3	1.205809
	qDz4	-10.9084
	qDz6	0.008226
	qDz7	-0.01437
	qDz8	0.721119
	qDz9	-0.03747
	qEz1	-12.8866
	qEz2	-1.85431
	qEz3	-91.2427
	qEz4	0.083939
	qEz5	10.0554
	qHz1	0.00641
	qHz2	0.006701
	qHz3	-0.36586
	qHz4	-0.22987
Combined Longitudinal		
	rBx1	10.93409
	rBx2	-3.99218
	rCx1	-0.57953
	rEx1	0.315684
	rEx2	5.234512
	rHx1	0.021448


Fy - SA
Fz (N)
170
600
860
1050
R25B (Fx)
Lateral Force (Fy) - kN
Slip Angle (SA) - deg
OptimumTire
Student sponsorship
by OPTIMUM G
vehicle dynamics solutions


Mz - SA
OptimumTire
Aligning Torque (Mz) - Nm
Slip Angle (SA) - deg
Fz (N)
170
600
1050
R25B (Fx)
Student sponsorship
by OPTIMUM
vehicle dynamics solutions


Fy - SA
OptimumTire
Fz (N)
170
600
1050
R25B (Fx)
Inst. Cornering Stiffness (d(Fy)/d(SA)) - N/deg
Student sponsorship by OPTIMUM G
vehicle dynamics solutions