Design of Integrated Suspension System For Bicycle

Aditya Ratnaparkhe[1], Rahul Ovhal[2], Sanket Pujar[3], Rujuta Shah[4], Prof. Mr. V. K. Aher[5]
[1, 2, 3, 4, 5] Dept of Mechanical Engineering
[1, 2, 3,4, 5] Pimpri Chinchwad College Of Engineering

Abstract- *This project presents the wheel which is designed such that the suspension system is integrated within wheel by replacing the conventional pre-tensioned spokes with elliptical loops which act like a spring for road noise reduction and higher shock-absorbing sensitivity thus offering a smoother ride. The elliptical springs are usually made up of a composite material carefully developed to offer optimum compression and lateral stability as well as strength and durability. The three loops in every wheel work along as a self-correcting system. This spring system between the hub and the rim of the wheel provides suspension that continuously adjusts to uneven terrain cushioning the rider from abnormalities in the road wheel. The spring configuration permits the torque to be transferred smoothly between the hub and the rim. In this project the material selection is done on the basis of its chemical composition and strength and fabrication of the loops is done using spring steel. The analysis is done on ANSYS Workbench 16.0 to determine the maximum principle stress, Equivalent stress (Von-mises) and deflection for static loading, life and factor of safety against fatigue loading and modal analysis for determining the natural frequencies for vibrations.*

Keywords- bicycle, integrated suspension, noise reduction suspension, floating hub

I. INTRODUCTION

Bicycles are the most favourite choice when it comes to causes like health, pollution and environment. Several researches have been done in order to make the ride comfortable. Different types of cycles have been developed for various applications like Commuter Bikes, Mountain Bike, and Racing bike. Loop wheel, which is designed such that the suspension system is integrated within wheel for shock-absorbing performance and better comfort. The conventional spokes in wheel is replaced by three elliptical loops, which are attached to designed hub. The material selected for loop suspension has property such as elasticity, toughness, resilience and fatigue strength, which improve the shock absorbing capacity. They reduce jolting and vibration, by as much as two thirds compared with a spoked wheel. The three loops in each wheel work together as a self-correcting system. This spring system between the hub and the rim of the wheel provides suspension that constantly adjusts to uneven terrain, cushioning the rider from bumps and potholes in the road. In effect, the hub floats within the rim, adjusting constantly as shocks from an uneven road hit the rim of the wheel. The spring configuration allows the torque to be transferred smoothly between the hub and the rim. The spring rate for wheels was specifically chosen.

Unlike suspension forks, which only work in one plane, this provide tangential suspension. That is, they work in every direction. So they respond to a force hit head-on in the same way as they do to a force from above or below. One does not experience the usual feeling of vibration up your arms, because they absorb and isolate you from the “noise” of the road. So you get less wrist and shoulder ache on long rides.

II. LITERATURE REVIEW

Redfield, Robin C. and Sutela, Cory, Wheels are subject to a wide range of loading conditions. The most moderate inputs in the radial direction typically arise from the mass of the rider, long wavelength ground unevenness, and low amplitude surface roughness. In the lateral direction, cornering loads may also be relatively moderate in magnitude. These smaller loads are primarily absorbed by rider body motion and tire deformation. More extreme excitations include radial and lateral loads caused by high frequency or step inputs: rocks, roots, and trail discontinuities. These larger loads induce significant stress on the wheel structure; damage from this stress accumulates over the life of the wheel and leads to part failure. [3]

Roues Artisanales, The modal analysis is done to determine the natural frequencies of the structure which is to be compared with the working loading frequencies. If the frequencies math at some point then the structure undergoes failure due to resonance. However, this is critical consideration for rotating members with high angular speeds. For additional safety such components are supported by rubber mountings for damping out unnecessary vibrations caused by disturbances carried by shock waves. [15]

M. L. Hull , D. S. De Lorenzo, Although the measured hub forces directly indicate the ground contact force during coasting, this direct relation does not apply during braking because braking causes a reaction force at the hubs.

Thus, to determine the ground contact forces during braking, the brake force component tangential to the wheel rim was also measured [1]

III. MATERIAL SELECTION

Material Properties Requirement:

- Toughness
- Resilience
- Fatigue life
- Elasticity

Considering the chemical composition, silicon percentage plays an important role.

Higher the percentage of silicon, higher is the toughness thus the fatigue resistance.

Factors affecting Mechanical properties [5]

- Carbon- Increase in carbon content increases hardness and strength and improves hardenability.
- Manganese- Increases strength, tensile strength, toughness.
- Phosphorous-Increases strength, hardness and toughness.
- Silicon-Increases Strength, hardness and toughness.

Table 1: Chemical composition of materials [5]

Grade	C	Si	Mn	S	P
En42	0.72-0.86	0.15-0.35	0.58-0.75	0.05 max	0.05max
En43	0.5	0.3	0.7	0.015	0.015
En45	0.55	1.75	0.75	0.05	0.05
En47	0.5-0.55	0.5-0.58	0.5-0.8	0.05	0.05

EN47 is selected based on chemical composition and strength of material.

Sut = 667.3 MPa   Syt = 412.3 MPa

Variation in mechanical properties of En47 when quenched and tempered [6]

Table 2: Variation of EN47 according to temperature

Tempering Temperature	UltimateTensile Strength(MPa)	Yield Strength(MPa)
400	1930.5	1689.2
600	1723	1572
800	1434	1330
1000	1158.3	1068
1200	944.58	841.16

IV. DESIGN OF WHEEL

Sketching of the wheel:

The dimensions of the loops were iterated keeping the required stiffness and space constraints for the operation of loops into considerations.

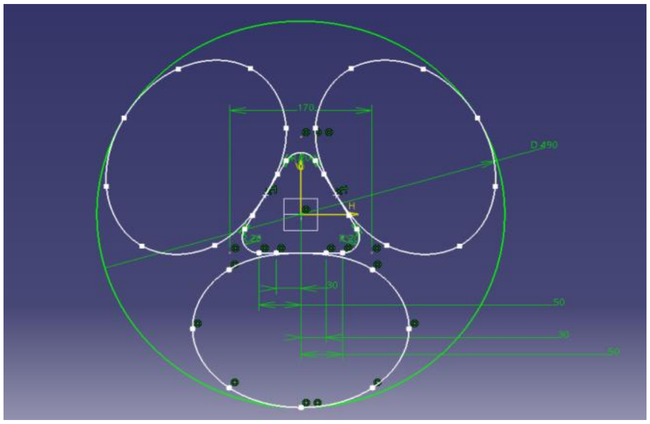


Figure 1: 2D sketch of the system

The Rim diameter was specified to be 530mm diameter. The effective Diameter remaining to include the loops after adding rubber mountings of 20mm thick on rim and the optimised hub dimensions was 490mm.

Accordingly, the Dimensions of the elliptical loop was iteratively selected to allow them to expand freely without touching adjacent components.

Dimensions of elliptical loop:

- Semi-major axis: 130mm
- Semi-minor axis: 100mm

Semi-major axis: 130m Semi-minor axis: 100mm

Semi-minor axis: 100mm

Geometric Calculations:

2D Co-ordinates of the ellipse was founded by using parametric equation of ellipse considering the semi-major and semi-minor axis dimensions.

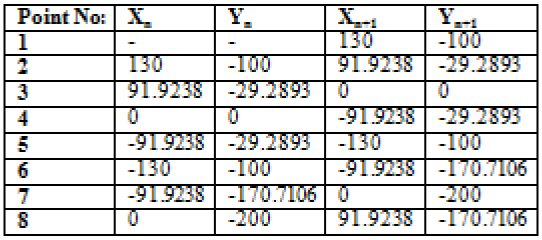
Parametric equation of ellipse is,

$$X_{n+1} = X_c + (X_n + X_c) \cos u - A/B\,(Y_n - Y_c) \sin u$$
$$Y_{n+1} = Y_c + (Y_n - Y_c) \cos u + B/A\,(X_n - X_c) \sin u \qquad [7]$$

Centre of ellipse (0,100)

Major axis of ellipse: 260mm. Hence, A=130
Minor axis of ellipse: 200mm. Hence, B=100
u= 450

Table 3: Co-ordinates of the points on the ellipse



Point No:	X_n	Y_n	X_{n+1}	Y_{n+1}
1	-	-	130	-100
2	130	-100	91.9238	-29.2893
3	91.9238	-29.2893	0	0
4	0	0	-91.9238	-29.2893
5	-91.9238	-29.2893	-130	-100
6	-130	-100	-91.9238	-170.7106
7	-91.9238	-170.7106	0	-200
8	0	-200	91.9238	-170.7106

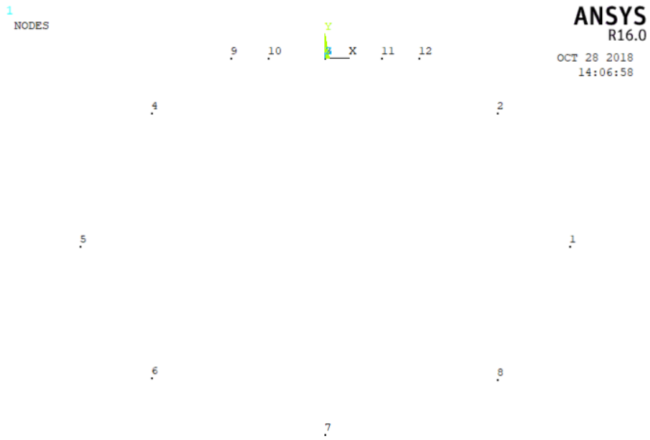


Figure 2: Plotting of points

3D Co-ordinates was founded out by considering the width of the loop and gap between them as 4mm.

The increments in z-coordinates are taken as (29/8), (29*2/8), (29*3/8),…

3D CAD Modelling was done using CATIA V5.

3D shape design command under the mechanical design was used, the spline was passed through these points and rib was generated along this spline.

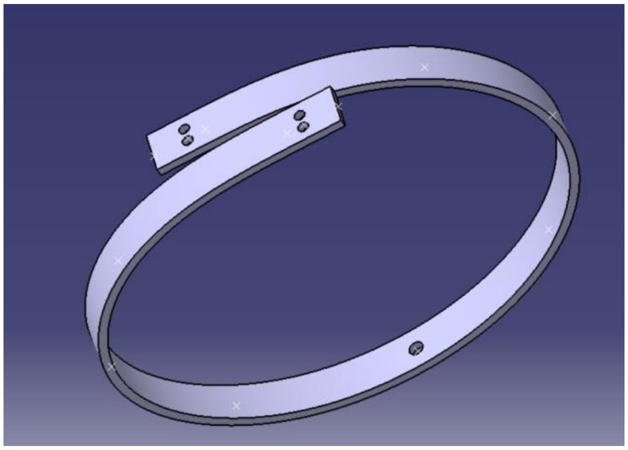


Figure 3: 3D CAD of loop spring

Analytical Calculations

Loop spring considered as leaf spring.

The static calculation was done such that the rider when seating the bicycle does not make the deformation too large and make the riding experience saggy. The suspension has to be stiff enough to support the dynamics of the moving body position of the rider. [12]

First considering it as a straight simply supported beam:

Design a leaf spring to carry a load of 1000N and placed over a span of 260 mm. The spring can deflect by 50mm. Consider, allowable bending stress for the spring material as 412.3 MPa and E=2*10^5 MPa.

Leaf Thickness (t) = (σ_{des} * L^2 / E * δ_{des})[2]

Now, for determining the central deflection of the plate that is initially curved we need to derive the expression

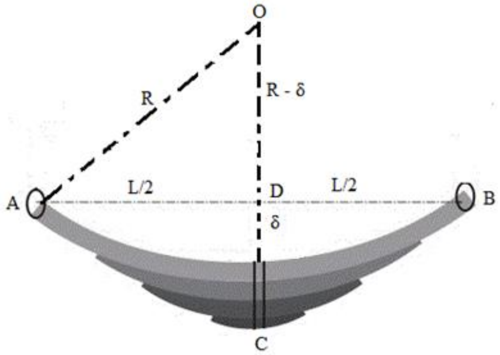


Figure 4: Curved plate

Let us consider
b = Width of each plate
n = Number of plates

L = Leaf spring span
t = Thickness of each plate of leaf spring
δ = Deflection of the top spring
R = Radius of the plate in which plates are bent initially
W = Point load acting at the centre of the leaf spring
σ = Maximum bending stress developed in the plate of leaf spring
A and B = Two ends of the leaf spring
C = Centre point of the leaf spring

Let us consider here the triangle AOD; we will have following equation as mentioned here

$AO2 = OD2 + AD2$
$R2 = (R - \delta) 2 + (L/2)2$
$R2 = R2 + \delta 2 - 2R. \delta + L2/4$
$R2 = R2 - 2R. \delta + L2/4$

We have neglected small term i.e. $\delta 2$

$2R. \delta = L2/4$
$\delta = L2/8R$

Let us remind here the bending equation and we can write here following equation as mentioned here

$\sigma / y = E/R$
$R = (E \times y) / \sigma$
$R = (E \times t) / 2\sigma$

Now we will use the above value of R in deflection equation in order to secure the expression for central deflection developed in the plate of leaf spring. [2]

$\delta = 2\sigma \times L2/8(E \times t)$
$\delta = \sigma \times L2/4E.t$
Now for,
Width = 25mm
Thickness=5mm
L=260mm

Maximum deflection was found out to be 6.96mm for σ = 412.3MPa

The deflection obtained analytically was calculated at 260mm eye to eye length of the leaf spring system, but in practice the loop will change its dimensions as it store energy so the deflection obtained is function of major axis length.
The max allowable deflection calculated by considering it as a leaf spring has limitations and assumptions like:

1) The eye to eye distance of the leaf support are constant however, in our case the distance between the two ends goes on increasing with central deflection.
2) The curvature of the leaf is constant however, as the leaf goes on deflecting the curvature changes .Hence, more approximate values is given by the software.

Standard sizes of leaf spring available:

Width (mm) : 25-80 mm in steps of 5mm Thickness (mm) : 2-8 mm in steps of 1mm, 10-16 mm in steps of 2mm
Hence, 5x25mm flat bar is selected.

The analysis was done on Ansys workbench 16.0

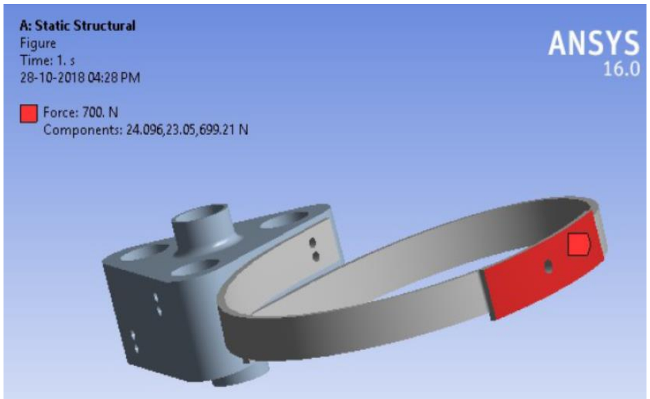


Figure 5: Application of Force

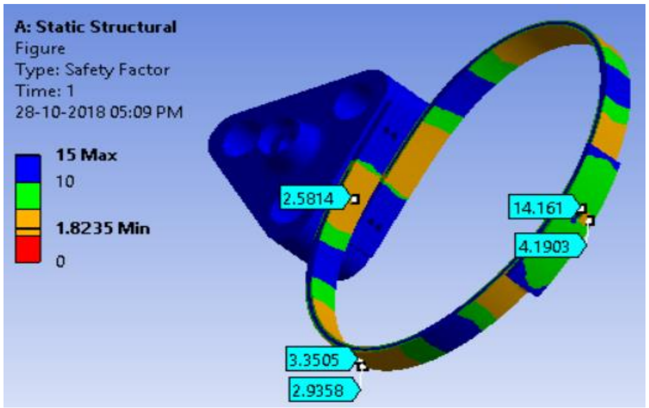


Figure 6: Safety Factor under load

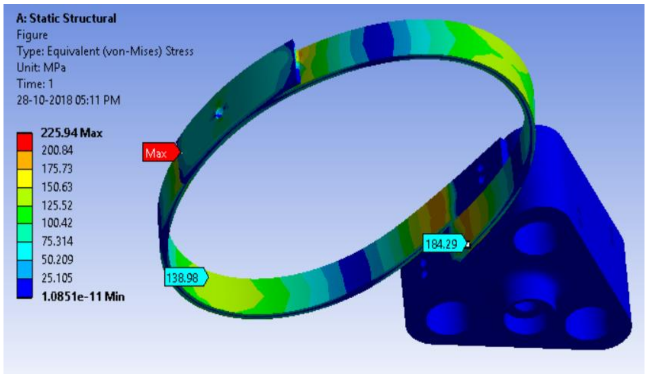


Figure 7:Von-Mises Stress

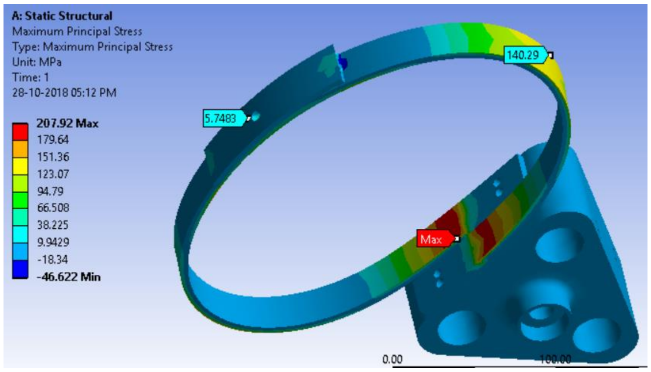


Figure 8: Maximum Principal Stress

The maximum principal stress and von-mises stress value was lower and hence design is safe in static loading.The max principle stress is found to be at intersection of leaf and hub; this can be avoided by placing a rubber damper between them to avoid metal-to-metal contact.

V. FATIGUE ANALYSIS

The most important consideration in design of spring element is fatigue life, this elastic component is designed such that the component will fail in fatigue loading only under intended mode of use.

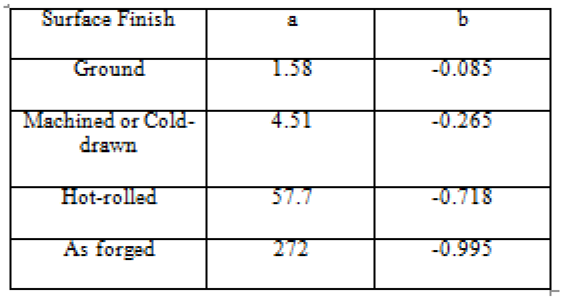
Analytical Calculations:

$S_e = K_a * K_b * K_c * K_d * (0.5S_{ut})$
K_a= Surface finish factor
K_b= Size factor
K_c= Reliability factor
K_d= Modifying factor to account for stress concentration.

For K_a

$K_a = a(Sut)^b$

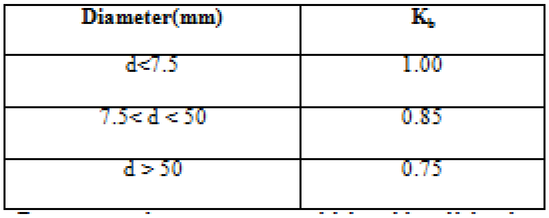
Table 4: Variation of surface finish factor according to process[10]



Surface Finish	a	b
Ground	1.58	-0.085
Machined or Cold-drawn	4.51	-0.265
Hot-rolled	57.7	-0.718
As forged	272	-0.995

For K_b

Table 5:Variation of diameter according to Kb [10]



Diameter(mm)	K_b
d<7.5	1.00
7.5< d < 50	0.85
d > 50	0.75

For a rectangular cross-section with b breadth and h height
$D_e = 0.808 * (b*h)^{0.5}$
For bending and torsion the equation is:
For 2.79mm < d < 51mm
$\mathbf{K_b = 1.24 * d^{-0.107}}$
For 51mm < d < 254mm
$\mathbf{K_b = 0.859-0.000873d}$
For axial loading, $K_b=1$
$K_c=0.897$ (considering 90% reliability)
Consider $K_d=1$.

S_{ut} for En47= 667.3MPa
$0.9(S_{ut})=600.57$MPa
$S_f = 135$MPa
$K_a =0.421$ $K_b = 0.9798$ $K_c = 0.897$ $K_d =0.8$
$S_e = K_a * K_b * K_c * K_d * (0.5S_{ut})$
=98.76MPa

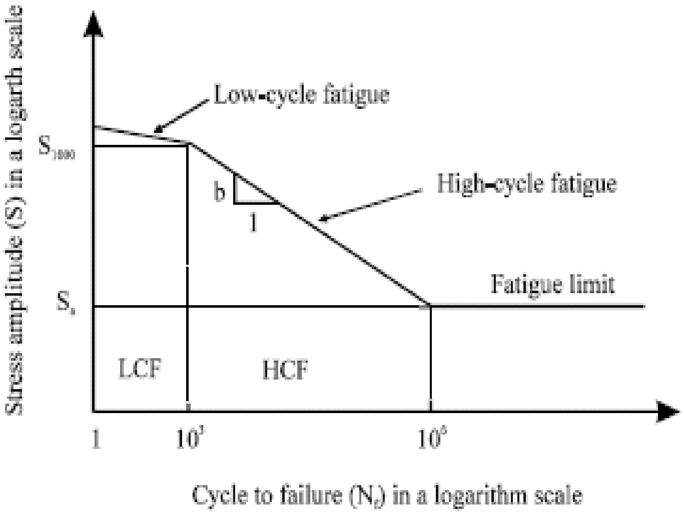


Figure 9: S-N curve

$$\frac{\log(600.57)-\log(135)}{\log(600.57)-\log(98.76)}=\frac{\log N-3}{6-3}\qquad[10]$$

N=3.02$\times 10^5$ cycles

Now, the fatigue load of alternation loads of 600N to -300N [4] was applied in the analysis setting, loading ratio was taken as 1.0 to -0.5. [13] [15]

The standard procedure and analysis setting was chosen from the Ansys nCode Handbook [13]

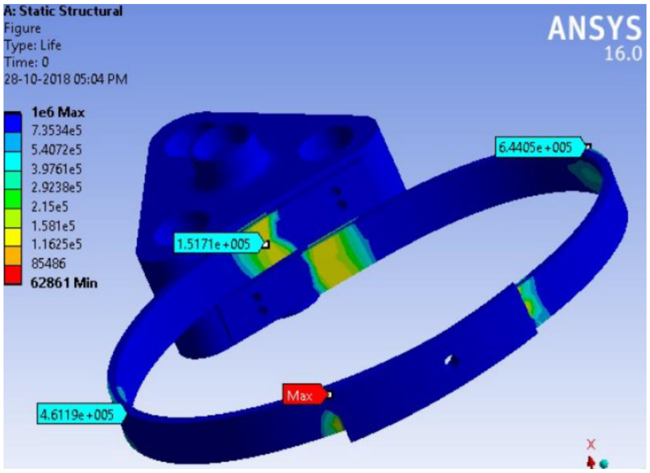


Figure 10: Life of component under fatigue

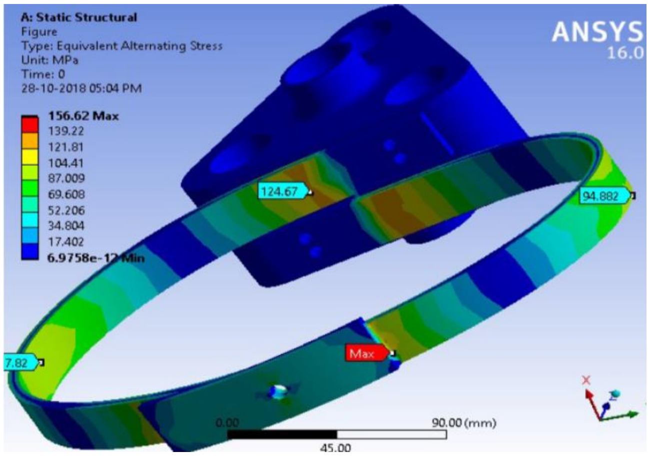


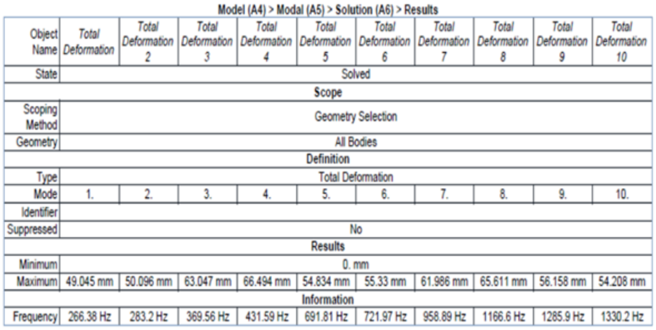
Figure 11: Stress under fatigue Equivalent Alternating

The results show life and equivalent alternating stress.The concentration is at the ends and at the contact region between hub and loop, which can be avoided by placing rubber damper to avoid metal to metal contact

VI. MODAL ANALYSIS

Modal Analysis is done using Ansys Workbench 16.0. Modal analysis is used to determine/study the response of structure for dynamic loading and determine natural frequency and mode shapes of structure. [10]

Table 6: Frequency Table



Model (A4) > Modal (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Total Deformation 2*	*Total Deformation 3*	*Total Deformation 4*	*Total Deformation 5*	*Total Deformation 6*	*Total Deformation 7*	*Total Deformation 8*	*Total Deformation 9*	*Total Deformation 10*
State	Solved									
Scope										
Scoping Method	Geometry Selection									
Geometry	All Bodies									
Definition										
Type	Total Deformation									
Mode	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Identifier										
Suppressed	No									
Results										
Minimum	0. mm									
Maximum	49.045 mm	50.096 mm	63.047 mm	66.494 mm	54.834 mm	55.33 mm	61.986 mm	65.611 mm	56.158 mm	54.208 mm
Information										
Frequency	266.38 Hz	283.2 Hz	369.56 Hz	431.59 Hz	691.81 Hz	721.97 Hz	958.89 Hz	1166.6 Hz	1285.9 Hz	1330.2 Hz

The minimum natural frequency amongst the 10 steps is 266Hz, which cannot be achieved since the wheel has to rotate at very high speed to match the frequency; hence the wheel is devoid of damage done by resonance.

VII. RIM SPECIFICATION

All data from BIS: 624:2003 Fourth revision ICS 43.150 October 2003, Bicycles Sectional Committee, TED [14]

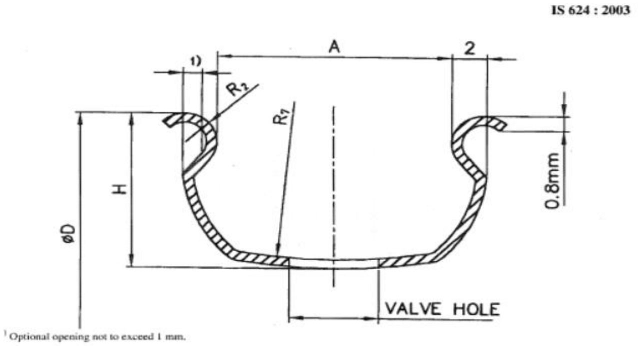


Figure 12: Rim Specifications

Rim Diameter: 530mm
Rim bead seat diameter: 540mm
Rim outer Width: 25mm
Type: Hooked Bead Rim

Rims shall be manufactured from cold-rolled carbon steel strips having the following physical properties when tested in accordance with IS 1608:

Ultimate tensile strength= Min 310 MPa
Yield strength= Min 185 MPa
Elongation= Min 25 percent on 50 mm [14]

VIII. DESIGN OF HUB

The Moment Acting on the free wheel type hub mounting was 50Nm [1].Force of 4000N was applied from below and the bearing housing was given frictionless support [1].The Hub had to be overdesigned to increase the dimensions in order to incorporate the loops in the system without them touching the adjacent components.The Hub was then optimised for weight reduction and various sections were iterated keeping in mind the following considerations:

1) Machinability by Vertical Milling Centre
2) Machining time and machining cost
3) Assembly of other components

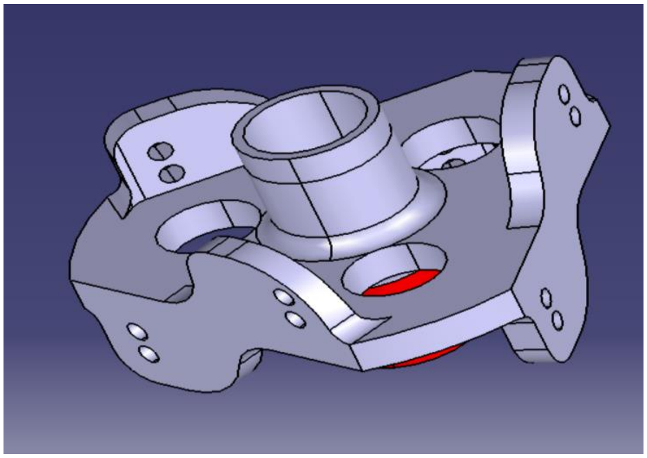
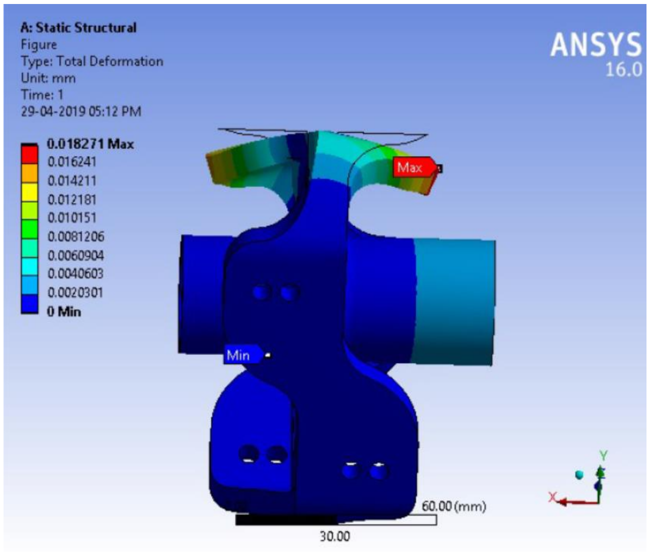
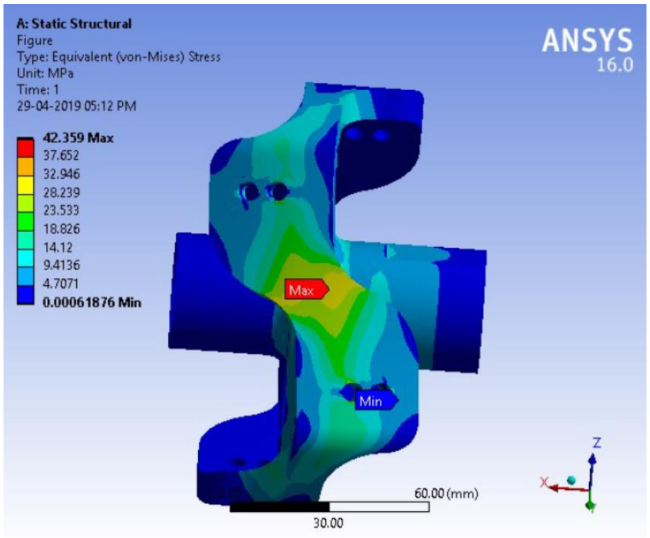


Figure 13: Hub



A: Static Structural
Figure
Type: Total Deformation
Unit: mm
Time: 1
29-04-2019 05:12 PM

Figure 14: Total deformation of rear hub on loading



A: Static Structural
Figure
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
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Figure 15: Von-Mises stress on rear hub

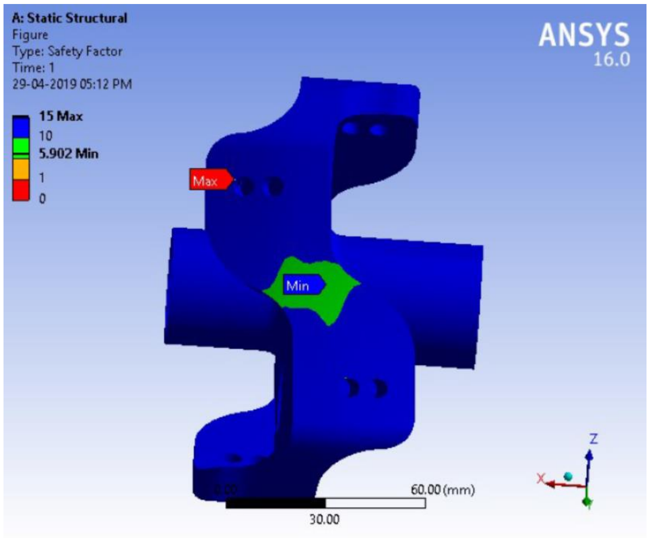

Figure 16: Factor of safety for hub

IX. FINAL ASSEMBLY

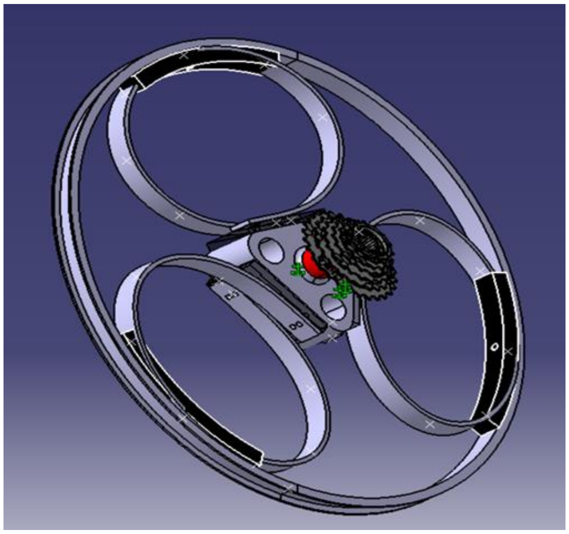

Figure 17: Final Assemby

X. ACKNOWLEDGMENT

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