Design and Analysis of a Sprocket-Hub Assembly

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***Abstract*: Sprockets are most widely used in automobile sector and in machinery. They might be integrated with the hub or might be two separate entities bolted or meshed together. They exist in various dimensions, teeth number and are made of different materials to ensure efficient power transmission sprocket-hub should be properly designed and manufactured. There is a possibility of weight reduction in sprocket- hub assembly. The designing of chain sprocket is done in Creo 3.0, analysis using Finite Element Analysis and using the results from FEA how the optimization of sprocket-hub for weight reduction has been done. We have used different grades of steel and alloys as their base material for both the sprocket and the hub. Static structural, Fatigue and Modal analysis done in workbench using Ansys 16.0. After a number of iterations and scanning through materials the sprocket hub assembly was then finalized and hence manufactured.**

***Keywords*: Sprocket, Analysis, Manufacturing, FEA, Design, Computer-Aided Engineering (CAD).**

1. Introduction

A sprocket is a profiled wheel with teeth that meshes with a chain. They are used in two wheelers and four and other mechanisms either to transmit revolving motion between two shafts wherever gears are unsuited. The most generic form of sprocket is come across in the bicycle where the pedal shaft carries a large sprocket-hub, which drives a small sprocket on the shaft of the rear wheel. Sprockets are of various designs, dimensions, teeth number and are made of different materials. Sprockets are also used for power transmission from one shaft to another where slippage is not needed. Sprockets are theoretically basic mechanical devices. However, their versatility leads to many contrasting style. Sprockets are offered in several materials and designs, depending upon the application of service requirements. Usually, there are two major ways of categorizing sprockets; the sprocket as it is or a sprocket with the hub whether integrated or bolted. For many applications, fabricated steel sprockets are suggested as offering the best combination of performance, availability, and price. These steel sprockets are provided for every chain tooth combination and are readily available.

ANSYS software is used for Finite Element Analysis of sprocket. This design of the sprocket has been experimentally validated before actual implementing on vehicle and rigorous testing of vehicle. Hence, extreme loads acting on teeth are calculated. Stress induced due to load must be less than the yield stress of the material. If stress becomes more than yield stress of material then there may be a possibility of failure. Therefore, static analysis was performed to ensure that the proposed design has factor of safety greater than 2. The results of the FEA are used further study of stress concentration and hence for optimization of the component for weight reduction. The modified design also analyzed before finalization.

2. Objectives

There will be a change in the gear ratio as required in the drive train system using the calculations and power and torque values from the engine. The sprocket will be detachable from the hub as it makes it easier for manufacturing and reduces cost and helps in easier serviceability. This sprocket assembly will undergo FEA to give us an idea of stress concentration. The sprocket assembly will be then optimized or weight reduction will be done to get better stress concentration. Increase in the top speed of the car and reduction of acceleration time will be achieved.

3. Methodology

The different types of sprocket assemblies will be examined for pros and cons of all the assemblies. The most suitable assembly will be selected and then used as a reference for design. Once the design is finalized with the required gear ratio found from our calculations. The material will be selected for the hub and the sprocket after the material is finalized it will go through a thorough FEA for different types of weight reduction or stress relieving iterations for max efficiency and low weight.

4. Design of Sprocket

A. Calculations of force

1) The force calculations are done as follows

Torque at crank after losses = 44 Nm

Torque at wheel = Torque at crank*primary gear ratio* 1stgear ratio*final drive ratio

= 44*2.071*2.5833*2.96 = 829 Nm

Therefore, torque on both wheels= 829 Nm

Torque on one wheel=829/2=414 Nm

Tyre radius= 230 mm

Loaded tyre radius= 230*0.8=184 mm

Force on one tyre= 414/0.184= 2250 N

2) To get number of teeth of sprocket we have

V=w*r

V=2*π*r*N/60

Considering V as =90 km/h

=25 m/s

Considering r=230mm and after load factor =184mm

Therefore, we get N2 =1298 rpm which is at the wheel

Consider N1=engine rpm

N2=wheel rpm

Considering n=11000 rpm of crankshaft with max power of 80 BHP

Let 'x' be the required sprocket ratio

N1/N2=x*2.073*1.44

Where x is the gear ratio of the required drive

8.84=x*2.073*1.44

x=3.2

therefore, from the sprocket table we have

Table 1

GEAR RATIOS FOR SPROCKETS

FRONT SPROCKET TEETH

<<< FASTER ACCELERATION <<<<<< >>>>>>MORE TOP END SPEED >>>

REAR SPROCKET TEETH

<<< FASTER ACCELERATION <<<<<< >>>>>>MORE TOP END SPEED >>>

	10	11	12	13	14	15	16	17	18	19
30	3.00	2.73	2.50	2.31	2.14	2.00	1.88	1.76	1.67	1.58
31	3.10	2.82	2.58	2.38	2.21	2.07	1.94	1.82	1.72	1.63
32	3.20	2.91	2.67	2.46	2.29	2.13	2.00	1.88	1.78	1.68
33	3.30	3.00	2.75	2.54	2.36	2.20	2.06	1.94	1.83	1.74
34	3.40	3.09	2.83	2.62	2.43	2.27	2.13	2.00	1.89	1.79
35	3.50	3.18	2.92	2.69	2.50	2.33	2.19	2.06	1.94	1.84
36	3.60	3.27	3.00	2.77	2.57	2.40	2.25	2.12	2.00	1.89
37	3.70	3.36	3.08	2.85	2.64	2.47	2.31	2.18	2.06	1.95
38	3.80	3.45	3.17	2.92	2.71	2.53	2.38	2.24	2.11	2.00
39	3.90	3.55	3.25	3.00	2.79	2.60	2.44	2.29	2.17	2.05
40	4.00	3.64	3.33	3.08	2.86	2.67	2.50	2.35	2.22	2.11
41	4.10	3.73	3.42	3.15	2.93	2.73	2.56	2.41	2.28	2.16
42	4.20	3.82	3.50	3.23	3.00	2.80	2.63	2.47	2.33	2.21
43	4.30	3.91	3.58	3.31	3.07	2.87	2.69	2.53	2.39	2.26
44	4.40	4.00	3.67	3.38	3.14	2.93	2.75	2.59	2.44	2.32
45	4.50	4.09	3.75	3.46	3.21	3.00	2.81	2.65	2.50	2.37
46	4.60	4.18	3.83	3.54	3.29	3.07	2.88	2.71	2.56	2.42
47	4.70	4.27	3.92	3.62	3.36	3.13	2.94	2.76	2.61	2.47
48	4.80	4.36	4.00	3.69	3.43	3.20	3.00	2.82	2.67	2.53
49	4.90	4.45	4.08	3.77	3.50	3.27	3.06	2.88	2.72	2.58
50	5.00	4.55	4.17	3.85	3.57	3.33	3.13	2.94	2.78	2.63
51	5.10	4.64	4.25	3.92	3.64	3.40	3.19	3.00	2.83	2.68
52	5.20	4.73	4.33	4.00	3.71	3.47	3.25	3.06	2.89	2.74
53	5.30	4.82	4.42	4.08	3.79	3.53	3.31	3.12	2.94	2.79
54	5.40	4.91	4.50	4.15	3.86	3.60	3.38	3.18	3.00	2.84
55	5.50	5.00	4.58	4.23	3.93	3.67	3.44	3.24	3.06	2.89
56	5.60	5.09	4.67	4.31	4.00	3.73	3.50	3.29	3.11	2.95
57	5.70	5.18	4.75	4.38	4.07	3.80	3.56	3.35	3.17	3.00
58	5.80	5.27	4.83	4.46	4.14	3.87	3.63	3.41	3.22	3.05
59	5.90	5.36	4.92	4.54	4.21	3.93	3.69	3.47	3.28	3.11
60	6.00	5.45	5.00	4.62	4.29	4.00	3.75	3.53	3.33	3.16
61	6.10	5.55	5.08	4.69	4.36	4.07	3.81	3.59	3.39	3.21
62	6.20	5.64	5.17	4.77	4.43	4.13	3.88	3.65	3.44	3.26

Lowering the ratio increases top end speed - Increasing the ratio increases acceleration and bottom end power.

Number of teeth=42

Chain pitch =15.875 mm

Sprocket diameter = 202.33 mm

Roller diameter = 10.22 mm

Sprocket thickness = 5.6 mm

B. Dimensions for the sprocket in computer-aided drawing

The procedure for designing a sprocket provides a method for generating solid models, of any standard sprocket given the pitch, teeth and thickness of the sprocket etc. by first sketching the profile.

From the table we have the following

1] P=Chain Pitch

P=15.875

2] N=No. of teeth

N=40

3] Dr=Roller Diameter

Dr=10.22mm

4] Ds=Curve Diameter

Ds=1.0005Dr+0.003

5] R=Ds/2

R=5.13705mm

6] M=0.8*Dr cos(35˚+60˚/N)

M=6.5723

7] T=0.8*Dr sin(35˚+60˚/N)

T=4.8632

8] E=1.3025 Dr +0.0015

E=13.313mm

9] W=1.4 Dr cos(180˚/N)

W=14.263

10]V=1.4 Dr sin(180˚/N)

V=1.122

11] Pd=Fig(sin/180˚)

Pd=202.33

12] B= 18˚-56˚/N

P = Chain Pitch

N = Number of Teeth

Dr = Roller Diameter (See Table)

Ds = (Seating curve diameter) = 1.0005 Dr + 0.003

R = Ds/2 = 0.5025 Dr + 0.0015

A $= 35° + \frac{60°}{N}$

B $= 18° - \frac{56°}{N}$

ac = 0.8 x Dr

M $= 0.8 \times Dr \cos(35° + \frac{60°}{N})$

T $= 0.8 \times Dr \sin(35° + \frac{60°}{N})$

E = 1.3025 Dr + 0.0015

Chordal Length of Arc xy $= (2.605\, Dr + 0.003) \sin(9° - \frac{28°}{N})$

$$yz = Dr\left[1.4\sin(17° - \frac{64}{N}) - 0.8\sin(18° - \frac{56°}{N})\right]$$

ab = 1.4 Dr

$$W = 1.4\, Dr \cos\frac{180°}{N}$$

$$V = 1.4\, Dr \sin\frac{180°}{N}$$

$$F = Dr\left[0.8\cos(18° - \frac{56°}{N}) + 1.4\cos(17° - \frac{64°}{N}) - 1.3025\right] - .0015$$

$$H = \sqrt{F^2 - (1.4Dr - \frac{P}{2})^2}$$

$$S = \frac{P}{2}\cos\frac{180°}{N} + H\sin\frac{180°}{N}$$

$$PD = \frac{P}{\sin\left[\frac{180°}{N}\right]}$$

C. Force Acting on each teeth

The force calculations are done as for tension on sprocket

$T_k = T_o * [\sin Ø/\sin(Ø+2β)]^{k-1}$

T_k = back tension

T_o = chain tension

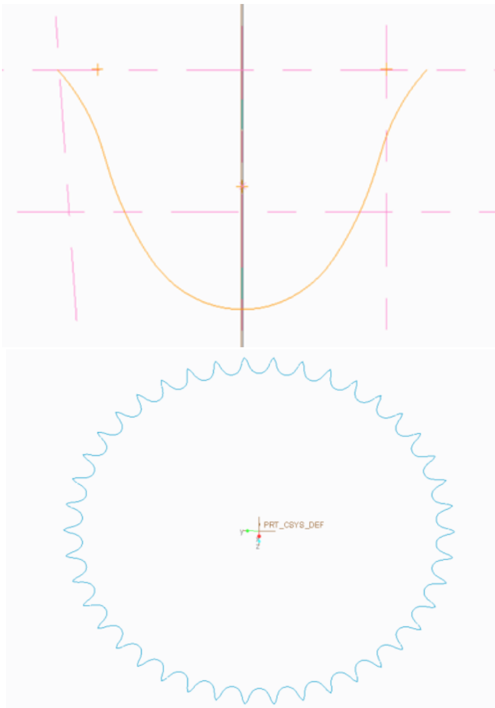
K is no of teeth the force is applied on

Ø = Sprocket min pressure angle = 17-64/42=15.4

2β = Sprocket tooth angle = 360/42=8.5

Table 2
Forces

Sr. no	Forces
1.	6857 N
2.	4407 N
3.	2833 N
4.	1821 N
5.	1822 N
6.	1821 N
7.	1170 N
8.	752 N
9.	483 N



Wire Diagram of Teeth Profile

5. Design of Hub

This iteration of the hub is designed using the space available between the differential mounts and the length of spline available on the differential to mount the sprocket hub. The diameter is set due to the restrains in the space available to use tools without an obstruction.

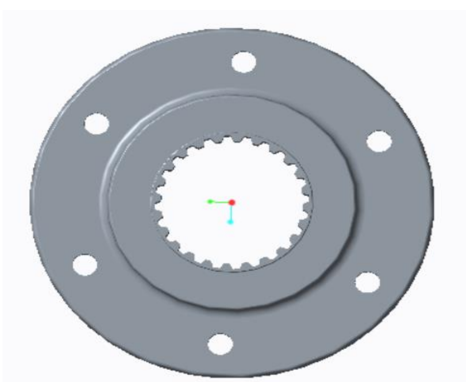


Fig. 1. Hub

6. Finite Element Analysis of a Sprocket

Finite element analysis (FEA) is an onscreen method for visualizing how a product reacts to real world forces, shows whether a product will fail, wear out or work the way it is anticipated. It is termed as analysis, but in the product improvement process, it is used to study what's going to happen when the product is used. Here, Static Analysis is done by using ANSYS 16.0 and boundary conditions are fitted to get desired solution.

A. *Meshing*

For meshing, part file of sprocket is imported to Ansys 16.0. As all the dimensions of the sprocket are measurable, the best element for meshing is the tetrahedral element. Meshing tool in Ansys workbench is used to create a very fine mesh with element size 2 mm after convergence with, Aspect ratio 7, Jacobian. 0.9, Warpage 12, Relevance centre 18, Growth rate 0.2 per. Fig 2 shows the meshed model of sprocket in Ansys.

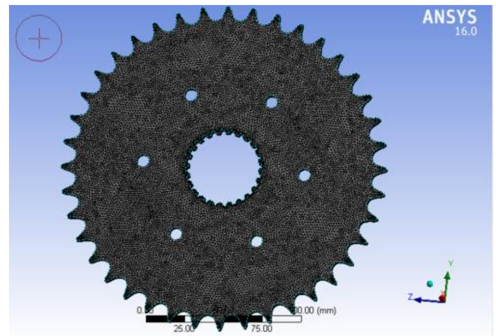


Fig. 2. Meshed Structure

B. *Boundary Conditions*

Subsequently meshing is accomplished, boundary conditions are applied. These boundary conditions are the reference points for calculating the results of analysis. The sprocket assembly is fixed from the splined region and hence the force is applied on a single tooth to give the stress values.

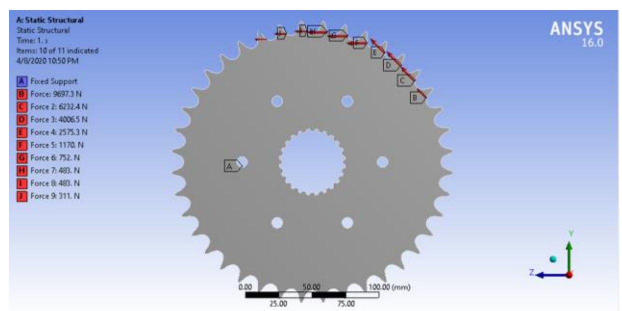


Fig. 3. Boundary Conditions

C. *Solution*

After meshing and boundary condition applied to the model, analysis is done in ANSYS 16.0 version. It calculated the deflection with respect to the boundary conditions applied and hence calculated the stress. Results are observed and subsequently changes are made according to high stress regions. If the stresses are afar the permissible limits then variations such as change in material of component or changes in design are made accordingly.

1) *Static Analysis*

The forces calculated are tangentially applies to the teeth of the sprocket and fixed constraints are applied at the bolt holes considering bolted joint. Analysis is done in Ansys Workbench 16.0. Plots of von-mises stress and deformation are as follows:

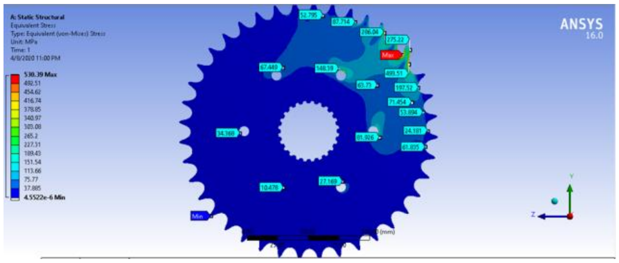


Fig. 4. Von misses stress plot

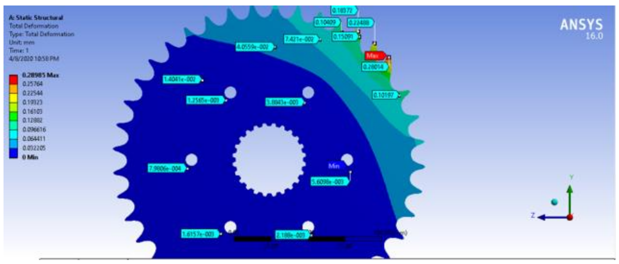


Fig. 5. Deformation plot

Here the calculated forces are applied on consecutive 10 teeth. The stress plot shows the stress flow and the maximum stress values of 530.99 Mpa and the deformation plot shows the maximum deformation of 0.28 mm which takes place. This is result is them analysed for further optimisation change of material etc.

7. Final Material Selection and Optimization

A. Material Selection

After a number of iterations with different types of materials like Mild Steel, stainless steel, steel alloys etc. with taking cost of manufacturing strength characteristics and hardness values of the materials and We have selected the final material En 08 for the sprocket and material En 24. The two materials have better strength characteristics than mild steel and other materials that we have tested.

Property	Value	Unit
Density	7480	kg m^-3
Isotropic Elasticity		
Derive from	Young's Modul...	
Young's Modulus	1E+07	psi
Poisson's Ratio	0.3	
Bulk Modulus	5.7456E+10	Pa
Shear Modulus	2.6518E+10	Pa
Field Variables		
Temperature	Yes	
Shear Angle	No	
Degradation Factor	No	
Tensile Yield Strength	500	MPa
Compressive Yield Strength	480	MPa
Tensile Ultimate Strength	800	MPa
Compressive Ultimate Strength	800	MPa

B. Final design of sprocket

After a few iterations for weight reduction, analysis and ease of machining this design was selected as the final design of the assembly.


Fig. 6. Final design

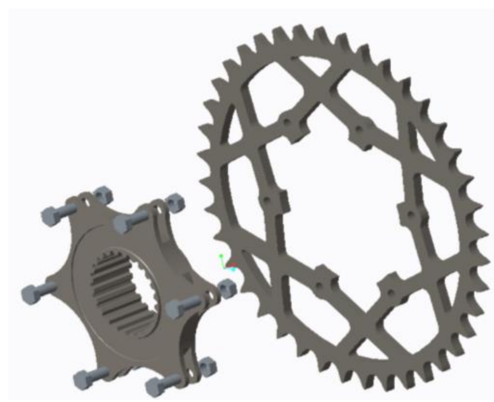


Fig. 7. Excluded view

8. Finite Element Analysis

A. Static Analysis

To validate the final weight reduction virtual Finite Element Analysis is done in Ansys Workbench 16.0. Where we treat bolted points as fixed nodes and apply variable forces on each tooth in contact with chain according to above mentioned calculation.

Meshing parameters:
Aspect Ratio =1.84 (avg.)
Jacobian = 0.8
Element Quality = 0.88
Warping Factor = 0.00

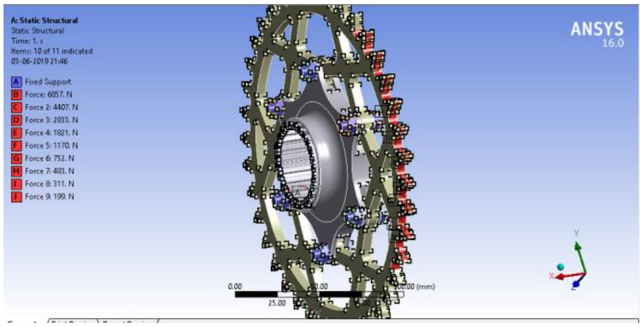


Fig. 8. Boundary Conditions

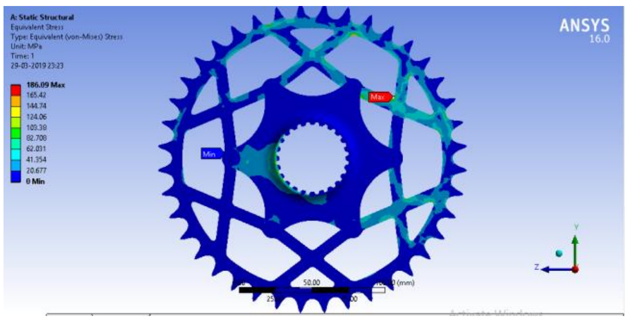


Fig. 9. Von misses stress plot

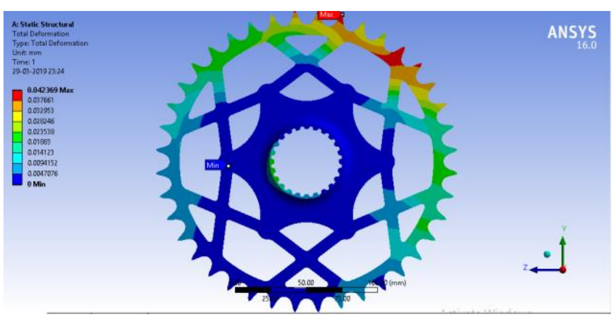


Fig. 10. Deformation plot

Thus, after numerous iterations and small design changes we were successful in shifting the stress concentration from the centre to 'X' (as shown in figure). The splines on double shear hub geometry is safe in shear. Hence maximum Von-misses stress according to plot is 186.09 Mpa. The maximum value of stress is less than the yield stress of EN 24, which results in factor of safety of 2.57. This is greater than its basic design mentioned above. While Maximum deformation obtained is 0.042 mm.

B. Model Analysis

Excited frequencies of engine running to its highest rpm are transferred to the sprocket and thus chances of it getting deformed at the mode points is more. In our case, the Yamaha R6 engine transmits rotation to primary reduction and from the primary reduction (i.e. primary sprocket) motion is transmitted to the secondary reduction (i.e. proposed sprocket hub assembly) with the help of a chain. Thus, there are possibilities that the excited frequencies transmitted by engine matches with the natural frequency of designed sprocket assembly. Hence resonance may occur at the respective modes. To find the mode points & corresponding deformation due to resonance modal analysis is performed using Ansys workbench 16.0. Modal Analysis is based on Fast Fourier Transform Series.

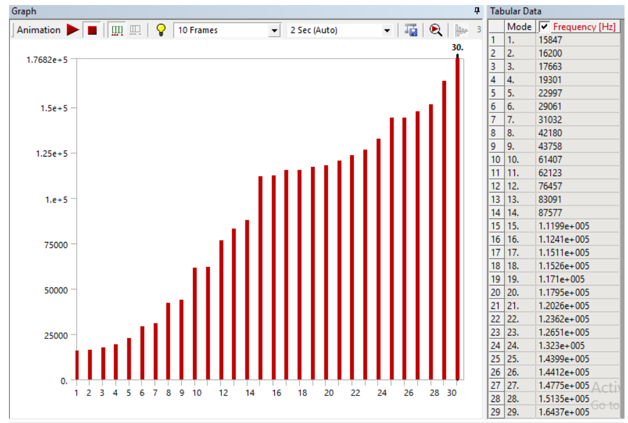


Fig. 11. Mode V/s Frequency graph

Table of frequency on Top 16 modes points on sprocket assembly,

Table 2

No. of Modes	Natural Frequency of sprocket assembly
1	15847
2	16200
3	17663
4	19301
5	22997
6	29061
7	31032
8	42180
9	43758
10	61407
11	62123
12	76457
13	83091
14	87577
15	1.12E+05
16	1.12E+05

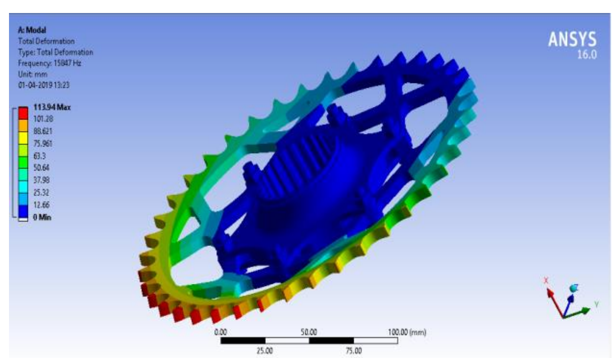


Fig. 12. Deformation on mode 1

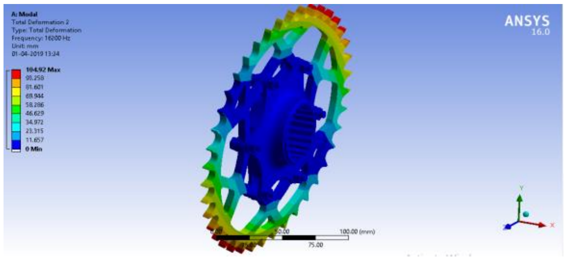


Fig. 13. Deformation on mode 2

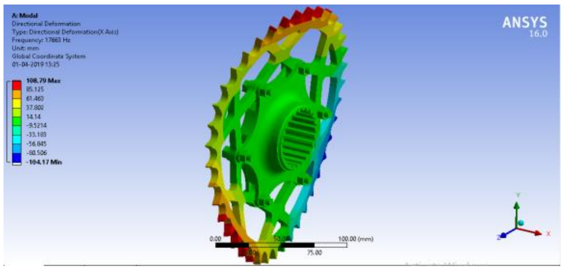


Fig. 14. Deformation on mode 3

C. *Fatigue Analysis*

Every designed product has a certain life. In case of our designed sprocket assembly it is under continues application of forces applied by chain to transmit motion from primary gear to drive shafts and hence the wheel. Due to of these variable distributed loads applied by chain on the teeth of the sprocket, cracks start to develop. After certain period of time the teeth shear from the dedendum of the sprocket. Thus, the assembly fails in Fatigue. Fatigue analysis is based on stress mean correction theory and many graphs are given to solve the endurance limit

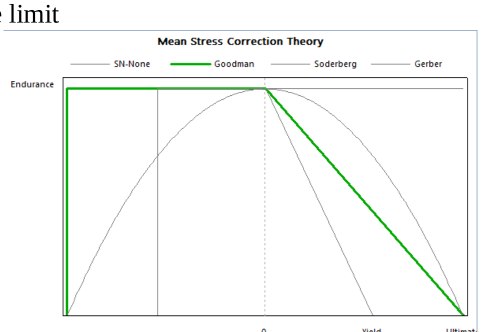


Fig. 15. Correction Theory graphs

Fatigue Analysis for sprocket:

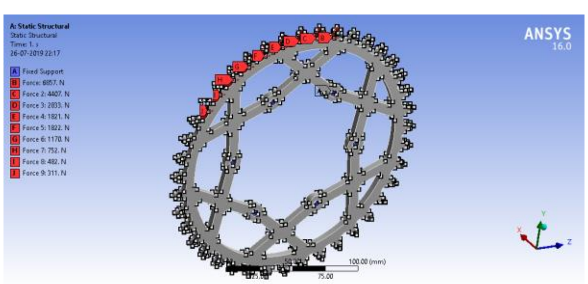


Fig. 16. Boundary Conditions

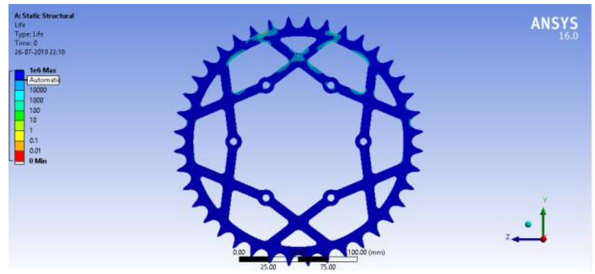


Fig. 17. Proposed Life of designed sprocket

The above figure shows that the maximum life (N) of proposed designed sprocket is 10^6 cycles.

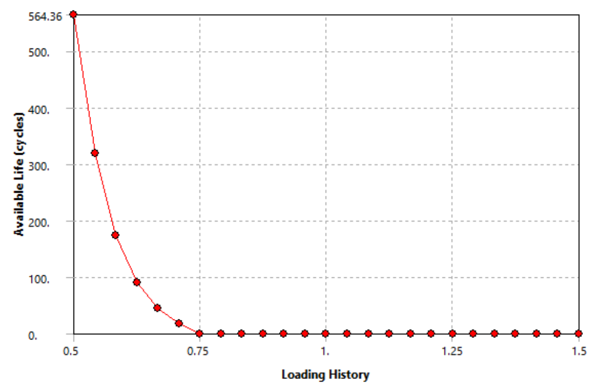


Fig. 18. Endurance Limit Graph

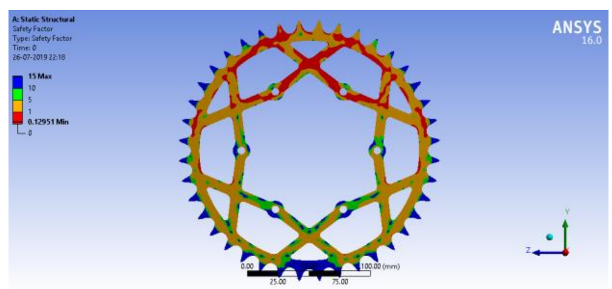


Fig. 19. Factor of safety

Fatigue Analysis for sprocket Hub:

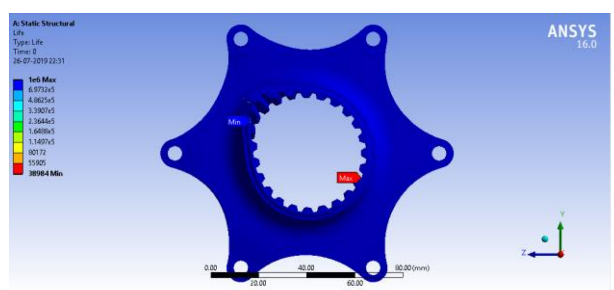


Fig. 20. Proposed Life of designed sprocket Hub

The above figure shows that the maximum life (N) of proposed designed sprocket hub is 10^6 cycles.

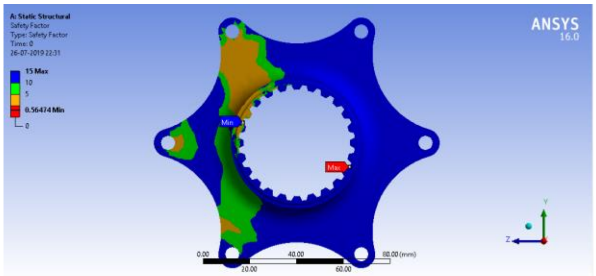


Fig. 21. Factor of safety

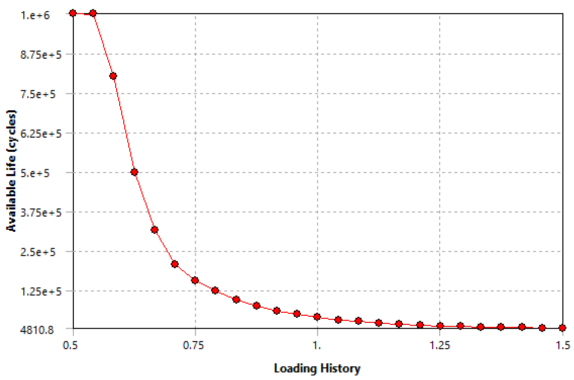


Fig. 22. Endurance Limit Graph

Above figure is the Endurance graph which represents the life of certain components. The factor of safety is decided within the range of 0 to 15 as per the analysis results in Fig 21. Hence FOS of sprocket hub is 3.98.

9. Conclusion

The design of the sprocket hub assembly has been finalized after a number of iterations. The material for the sprocket is EN 08 and EN 24 for the hub. The analysis of the parts are also completed which shows that the Sprocket hub assembly is safe with combine factor of safety of 2.57. The weight was reduced by 98% of the initial after weight reduction and optimization. Furthermore, materials maybe selected for better strength to weight ratio.

References

[1] Nikhil P. Ambole and P. R. Kale, “Finite Element Analysis Carbon Fiber Sprocket using ANSYS”, International Journal for Scientific Research & Development, Vol. 4, Issue 05, August 2016.
[2] Parag Nikam and Rahul Tanpure, “Design Optimization of Chain Sprocket Using Finite Element Analysis”, Int. Journal of Engineering Research and Application, Vol. 6, Issue 9, (Part-5) September 2016, pp.6669
[3] Pooja R Phule and Shyam P. Mogal, “Design and Performance Evaluation of Chain Wheel Drive of Bicycle by Using Alternate Material”, International Engineering Research Journal, pp. 105-110.
[4] Yasir Afzal, Vandana Jha and Anil Mohapatra, “A Comparative Study Based on ANSYS Analysis of Existing Sprocket’s Material with High Performance Engineering Plastic Materials”, International Research Journal of Engineering & Applied Sciences, Volume 2, Issue 3, July 2014, pp. 1-7.
[5] Ebhota Williams S, Ademola Emmanuel and Oghenekaro Peter, “Fundamentals of Sprocket Design and Reverse Engineering of Rear Sprocket of a Yamaha CY80 Motorcycle”, (IJET) – Volume 4 No. 4, April, 2014.
[6] V. B. Bhandari, “Design of Machine Elements.”
[7] http://www.xs650.com/threads/handy-gear-ratio-chart.51530/
[8] http://www.gearseds.com/files/design_draw_sprocket_5.pdf