RESEARCH ARTICLE OPEN ACCESS

Design Optimization Of Chain Sprocket Using Finite Element Analysis

Parag Nikam[1], Rahul Tanpure[2]
[1&2]*Department of mechanical Engineering, Smt. Kashibai Navale College of Engineering, Pune, India.*

ABSTRACT
Chain sprocket is one of the important component of chain drive for transmitting power from one shaft to another. To ensure efficient power transmission chain sprocket should be properly designed and manufactured. There is a possibility of weight reduction in chain drive sprocket. In this study, chain sprocket is designed and analysed using Finite Element Analysis for safety and reliability. ANSYS software is used for static and fatigue analysis of sprocket design. Using these results optimization of sprocket for weight reduction has been done. As sprocket undergo vibration, modal analysis is performed.
Keywords: Chain sprocket, FEA, Static analysis, Fatigue analysis, ANSYS

I. INTRODUCTION

In an automotive vehicle, engine produces the power which is transferred to the drive shaft. Chain drive is one of the commonly used drive train to transfer this power. Chain assembly consist of chain, driving sprocket and driven sprocket. The driving sprocket is connected to engine output shaft, which transfer power to driven sprocket by chain. Further this driven sprocket transfer power to drive shaft. Therefore in chain assembly driving sprocket has a chance for design and optimization for weight reduction. Due to high power transfer and high speed of rotation, high stress induces in sprocket teeth, also high speed leads to the vibrations. Hence it is important to designand manufacture sprocket properly, also mounting of sprocket is important.

While transferring power from driving to driven sprocket, chain exerts high load on sprocket teeth.So, maximum loads acting on teeth are calculated.Stress induced due to load should be less than the yield stress of the material. If stress becomes more than yield stress of material then there is a possibility of failure. Hence static analysis was performed to ensure that the proposed design has factor of safety greater than one. Also due to cyclic load acting on the sprocket from chain, it is important to test the sprocket for fatigue loading. In fatigue analysis fatigue life of sprocket is calculated and it is ensured that the minimum fatigue life is higher for safe use of sprocket for sufficient time period. After the minimum fatigue life, crack in the component initiated, which further increases with time and leads to failure of component. Therefore it is important for any component to have sufficient fatigue life.

FEA is used to perform the static analysis and fatigue analysis of component.This ensures the safety and reliability of component. The results of the FEA are used further for optimization of the component for weight reduction. The modified design also re-analysed before finalization. ANSYS software is used for FEA analysis of sprocket. This design of the sprocket has been experimentally validated after actual implementing on vehicle and rigorous testing of vehicle. Further sprocket design tested for vibrations, because vibrational forces also plays vital role in sprocket design. Modal analysis ensures that resonance frequencies of sprocket are out of Operating range.

II. CALCULATIONS

The formula used to calculate the force on each tooth of the sprocket is

$T_k = T_0$ *(sin φ / sin(φ+ 2)^k-1

Where:
T_k= Back tension at tooth k
T_0 = Chain tension = 6572.68N
φ= Sprocket minimum pressure angle
17 – 64/N = 15.57°
N = Number of teeth on driven sprocket = 45
2β= Sprocket tooth angle (360/N) = 8
K = the number of engaged teeth
= (angle of wrap *N/360) = 15

The general recommendation is to use 1/3.5 of the allowable tension as the back tension (T_k).

The maximum chain tension will act on the first teeth and then it decreases continuously. It is assumed that force acting after 10teeth is negligible.

By above method we can calculate forces on 10 consecutive teeth as follows:

Tooth number	Force (Newton)
T1	1177.9
T2	1251.9
T3	846.16
T4	567.99
T5	381.27
T6	255.9
T7	171.79
T8	115.31
T9	77.4
T10	51.96

Fig.1 Forces

III. MATERIAL SELECTION

Material selection is important consideration, due to strength and weight of sprocket. Mild steel was used to ensure sufficient strength of component.

Properties of mild steel
Young's Modulus = 2* e^11 Pa
Poisson's Ratio = 0.3
Density = 7850 kg / m^3

IV. PRELIMINARY DISIGN

CAD model with required dimensions and standard specifications was created in Solidworks 15.

Meshing tool in ansys workbench was used to create a very fine mesh with element size 1.5mm.

Fig.2 Meshing

a) Static Analysis

Calculated forces are applied on teeth surfaces with direction tangential to pitch circle of sprocket teeth. Also fixed constraints are applied at bolt holes. Analysis was done in Ansys Workbench 16.0.

Plots showing von-mises stress and deformation are as follows:

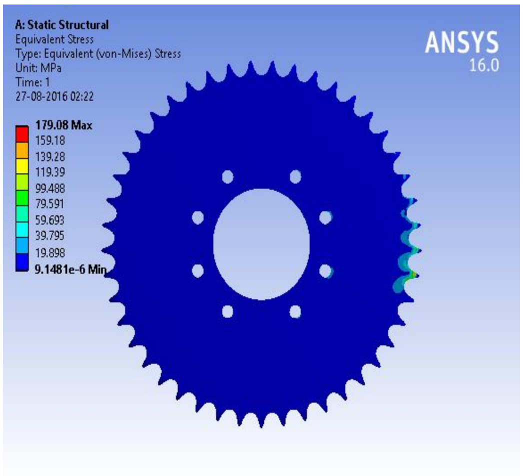

Fig.3 Von-mises stress plot

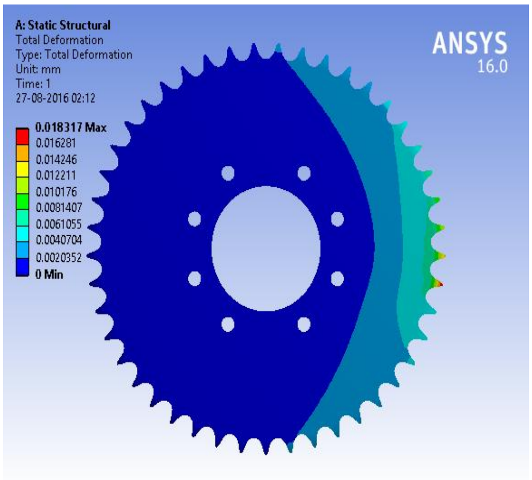

Fig.4 Deformation plot

Maximum Von-mises stress according to plot is 179.08Mpa. The maximum value of stress is less than the yield stress of mild steel, which results in factor of safety greater than 1.While Maximum deformation obtained is 0.01831mm. This maximum deformation appears at point which is subjected to maximum force.

The above stress and deformation plots used for removing material for optimization.

b) Fatigue Analysis

Fatigue analysis was performed to calculate the fatigue life of sprocket. The first evidence of crack obtains after the minimum fatigue life. Hence it is important considering fatigue life for component design.Fatigue tool from ANSYS Workbench was used for fatigue life calculation. Stress-life (S-N curve) analysis was performed;zero based force with goodman mean stress theory was used for high accuracy of result.

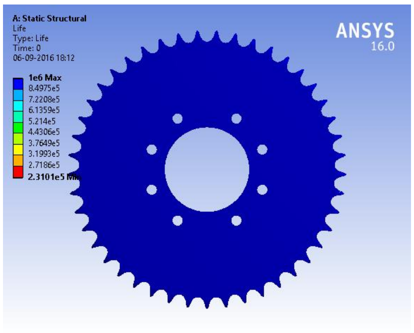

Fig.5 Fatigue life plot

From the above plot, the minimum fatigue life comes more than e^5 cycles, which is very high and can be considered safe for practical application.

V. MODIFICATION

By using results of analysis of preliminary design optimization for weight reduction was done. Material removed such that it does not affect the performance and safety of sprocket.

The modified sprocketalso fine meshed in ANSYS Workbench and further analysed.

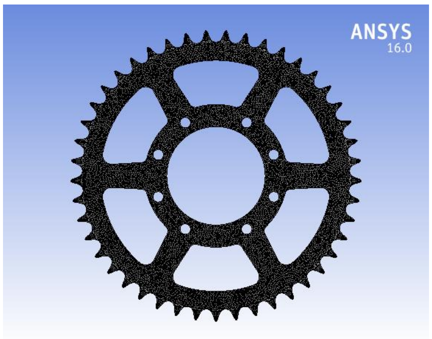

Fig.6 Modified model mesh

VI. MODIFIED DESIGN

a) Static Analysis

Loading conditions and boundary conditions for modified sprocket kept constant. Von-Mises stress and deformation for modified sprocket comes as follows:

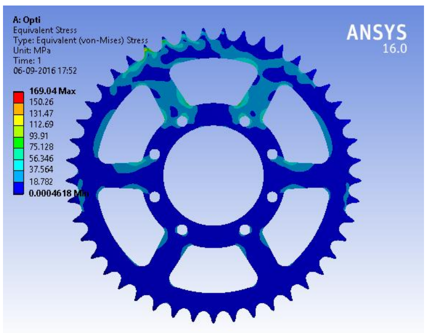

Fig.7 Von-mises stress plot

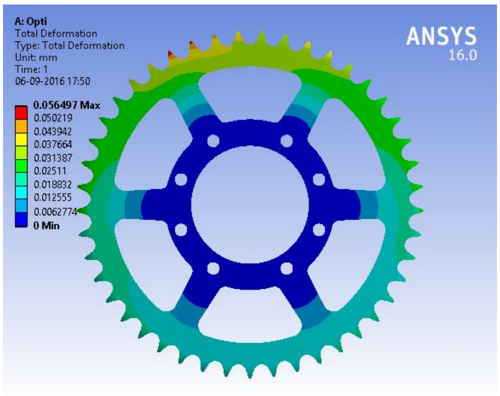

Fig.8 Deformation plot

From above plots it is seen that due to modification, total deformation of sprocket was increased to 0.0564mm. which is still negligible. This also results in reduction of von-Mises stress to 169.04MPa. Hence modified design was under safety limit with successful weight reduction.

b) Fatigue Analysis

Similar to preliminary design, fatigue analysis of modified sprocket was done to calculate the fatigue life of sprocket. Which again should be sufficiently high.

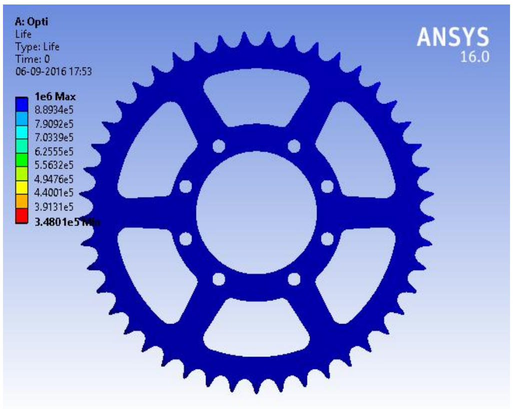

Fig.9 fatigue life plot

Hence from above fatigue life plot minimum fatigue life was in range of e^5 cycles, which is sufficiently high. Therefore, modified design was safe to use.

VII. MODAL ANALYSIS

Due to very high speed of rotation, chain sprocket is subjected to very high vibrational forces. Hence vibration analysis is important factor in sprocket design for safety. Modal analys was performed to calculate natural frequencies and mode shape of both preliminary and modified sprocket. Mode shape obtained for both the designwas same but natural frequencies differ.

Natural frequencies for both preliminary and modified design compared as follows:

Frequency	Preliminary design (Hz)	Modified design(Hz)
1	1665.5	1024.6
2	1679	1041.8
3	1774.5	1114.4
4	1883.5	1229.3
5	1970	1286.1
6	2492.6	1807.3

Fig.10 Comparision of natural frequencies

It is observed that natural frequencies for modifies sprocket are less than that of preliminary sprocket design. The amplitudes of free vibration at a particular frequency are more for the preliminary design and it is lesser for the modified sprocket design. Therfore the modified sprocket’s response to free-vibrations is better.

VIII. CONCLUSION

The design of sprocket has been succesfuly optimized with weight reduction of 15.67%. Also von-mises stress of modified design is lesser than preliminary design with little increase in deformation, which ultimately results in the safety and reliability of design. To further increase factor of safety of the sprocket different material with higher strength can be used.

REFERENCES

[1]. *The Complete Guid to Chain* (U.S. Tsubaki, Inc., Wheeling, Illinois 1997)
[2]. Saeed Moaveni, *Finite element analysis, theory and application with Ansys*(Prentice-Hall, Inc. 1999)
[3]. V.B. Bhandhari, *Design Of Machine Element* (McGraw Hills Education pvt. Ltd. 1994)
[4]. Rexnord (n. d.). *Chain Drive Design: A guideline to calculating and designing chain drives with a view to application-related criteria*.
[5]. Ebhota Williams S, Ademola Emmanuel, Oghenekaro Peter,*Fundamentals of Sprocket Design and Reverse Engineering of Rear Sprocket of a Yamaha CY80 Motorcycle*(International Journal of Engineering and Technology Volume 4 No. 4, April, 2014)
[6]. Kurt M. Marshek, Mohammad R. Naji, *Analysis of Sprocket Load Distribution* (Mechanism and Machine TheoryVol. 18, No. 5, 1983)
[7]. Nikravesh, P.E.*Computer-aided analysis of mechanical systems.*(Prentice Hall, Englewood Cliffs 1988)