Design and analysis of axle under fatigue life loading condition

Research Paper

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ABSTRACT

Axle is a critical part of suspension system. Due to variation in load axle is failed in fatigue. The scope of present work is to find out the fatigue life of axle which is used in race car. An axle is a non-rotating member, usually of circular cross-section for transmitting power. It is supported by hub. It is subjected to torsion, and bending in combination. The stress on the axle at a particular point varies with the irregularities of road by introducing fatigue. For finding out the fatigue life I am using Goodman method for analytical approach and FEA analysis done on ANSYS workbench software.

Keyword : - *Axle, Fatigue life, Goodman method, FEA analysis..*

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1. INTRODUCTION

The term suspension seems an odd one when considering the function in a modern vehicle, as the vehicle body appears to sit on rather than be suspended from the mechanism. Some authors have noted that the name relates back to the days of the stagecoach where an attempt was made to improve the abominable ride comfort over very long journeys by suspending the coach body on leather straps from comer posts attached to the chassis frame. Hence the concept of a suspension system took early form. In its simplest form, a modern road vehicle suspension may be thought of as a linkage to allow the wheel to move relative to the body and some elastic element to support loads while allowing that motion.

An axle is a non-rotating member, usually of circular cross-section for transmitting power. It is supported by hub. It is subjected to torsion, and bending in combination. The stress on the axle at a particular point varies with the irregularities of road by introducing fatigue. Even a perfect component when repeatedly subjected to loads of sufficient magnitude, will eventually propagate a fatigue crack in some highly stressed region, normally at the surface, until final fracture occurs. According to Osgood all machine and structural designs are problems in fatigue [1]. Failure of an elevator shaft due torsion-bending fatigue was given in [2]. The failure of a shaft due improper fastening of support was explained in [3]. Accurate stress concentration factors for shoulder fillet in round and flat bars for different loading conditions are given in [4]. Failure analysis of a locomotive turbocharger main-shaft and rear axle of an automobile was discussed in [6].

2. THEORY

Here, axle is simply supported in hub at two ends with subjected load from type of car.

A. Selection and Use of Failure Theory

Here select the Distortion energy theory for fatigue failure analysis to find maximum stress values because there is combined loading of bending and torsion. Distortion energy theory is used when the factor of safety is to be held in close limits and the Cause of failure of the component is being investigated. This theory predicts failure most accurately for ductile material. But design calculations involved in this theory are slightly complicated as compared with other theories of failure. The below equation (1, 2) is for design of shaft for fluctuating load calculated von-Mises stress. According to the distortion energy theory.

$$\sigma eq = \sqrt{(\sigma bmax)2 + 3(\tau max)3} \quad (1)$$

From, Design of safety,

$$\sigma eq = \frac{Syt}{fs} \quad (2)$$

Where, σeq =Equivalent stress (MPa)
$\sigma bmax$ =maximum bending stress (MPa)
τmax =maximum shear stress (MPa)
Syt=yield strength (MPa)
fs =factor of safety

B. Modified Goodman Method

The modifying endurance limit of the axle is found using Modified Goodman equation by taking mean stress in to account. Modified Goodman curve is a plot between the mean stress along X-axis and amplitude stress along Yaxis as shown in fig.1 and the equation (3) is represented as below

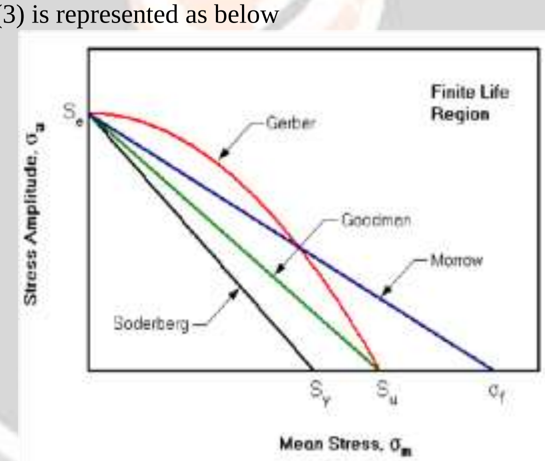

Fig.1 Fatigue diagram showing various criteria of failure.

By Modified Goodman Equation,

$$\frac{Sa}{Se} + \frac{Sm}{Syt} = 1 \quad (3)$$

Factor of safety is calculated for High cycle Fatigue applications from above equation (3).
We know that;
Fatigue failure safety is,
Factor of safety < 1 Design is fail
Factor of safety > 1 Design is safe.
Where,
Se=Modified endurance limit (MPa)

C. Fluctuating Stresses-Design for Finite and Infinite Life

There are two types of problems in fatigue design- (i) components subjected to completely reversed stresses, and (ii) components subjected to fluctuating stresses. The mean stress is zero in case of completely reversed stresses. But, in case of fluctuating stresses, there is always a mean stress and the stresses can be purely tensile, purely compressive or mixed depending upon the magnitude of the mean stress. Such a problems are solved by Modified Goodman diagram, which will be discussed in section B. The design problems for fluctuating stresses are further divided into two groups (i) design for infinite life, and (ii) design for finite life.

D. Material Properties

The CAD model of the shaft with its components is shown in fig.2.The material of the shaft under consideration is steel. Mechanical properties are shown in Table.1.

Table.1
Material Properties of axle

Physical Properties	Values
Modulus of elasticity	200GPa
Tensile strength	455MPa
Yield strength	250MPa
Poisson’s ratio	0.3

Fig.2 CAD model of hub axle

II. FATIGUE ANALYSIS BY ANALYTICAL APPROACH

In this section, calculated the von-Mises (equivalent) stress of factor of safety of number of cycle resp.

Initially, calculated Maximum and minimum bending moments at different points,

$(Mb)max$ = 171000 N -mm

$(Mb)min$ = 57000 N-mm

To find Mean & Amplitude Stresses

$(Mb)_m = \frac{(Mb)\max + (Mb)min}{2}$ (4)

$= 11.40 \times 104\ N.mm$

$(Mb)_a = \frac{(Mb)\max - (Mb)min}{2}$ (5)

$= 5.70 \times 104\ N.mm$

$\sigma_{Xm} = \frac{32(Mb)m}{\pi d^3}$ (6)

$= 145.15\ N/mm2$

$\sigma_{Xa} = \frac{32(Mb)a}{\pi d^3}$

$= 37.16\ N/mm2$

Taking kf=1 [No change in c/s of axle]

$\sigma m = \sqrt{(\sigma_{Xm} \times Kf)2 + 3(\tau xm \times kf)2}$ (7)

Axle is stationary element

$\tau xm = 0$

$\sigma m = 145.15\ N/mm2$

$\sigma a = 37.16\ N/mm2$

So, we can say that,

The von-Mises/equivalent stresses are145.15 $N/mm2$

$\tan\theta - \frac{\sigma u}{\sigma m}$ > $\tan\theta - \frac{su}{sm}$

$\tan\theta = 0.5°$

$\theta = 26°\ 33'$

To find Endurance Strength 'Se'

$Se = k\ load \times ksize \times k\ surface \times k\ temp \times$

$k\ reliability \times kd \times kstress - concentiation \times Se'$

$Se' = 0.5\ sut$ (8)

$Se' = 227.50\ MPa$

$k\ sunface = 4.51(455)\ {-0.265} = 0.891$

Ksize=1.2587(d)-0.1133=0.874

Kload=1

Ktemp=1.0000

Kstress-concentration= $\frac{1}{Kf}$=1

Kreliability=90% =0.897

Se = 1 × 0.874 × 1 × 0.891 × 0.897 × 1 × 227.50

$\boldsymbol{Se = 158.91\ N/mm2}$

By modified goodman diagram.

$$\frac{S_a}{Se} + \frac{S_m}{Syt} = 1 \qquad S_a = 0.5\,S_m$$

$$\frac{0.5\,S_m}{158.91} + \frac{S_m}{250} = 1$$

$$3.146 \times 10^{-3}\,S_m + 4 \times 10^{-3}\,S_m = 1$$

$$S_m = 139.94\ N/mm^2$$

Sa = 69.97 N/mm 2

$$F.O.S = \frac{S_a}{\sigma_a} = \frac{69.97}{37.16} \quad (9)$$

$$F.S = 1.88 > 1$$

$\therefore \boldsymbol{Note : F.O.S \geq 1\ \ Design\ is\ safe}$

To find Number of Cycles from S-N Construction

$$S_f = \frac{\sigma a \times sut}{sut - \sigma m} \quad (10)$$

$$= \frac{37.16 \times 455}{455 - 145.15}$$

$$S_f = 44.41 MPa$$

0.9 sut = 409.5 MPa

Log 10(0.9 sut) = 2.612

Log 10(Se) = 2.2011

Log 10(Sf) = 2.612

$$\frac{\log 10\ (Sf) - \log 10\ (Se)}{6 - log10(N)} = \frac{log10(0.9Sut) - log10(Se)}{6-3} \quad (3.7)$$

$$\frac{2.612 - 2.2011}{6 - log10(N)} = \frac{2.612 - 2.2011}{3}$$

log10 (N) =7.045

N=11.09 ×106 cycles

Since, Infinite number of cycles more than 1x 106 cycles.

3. FATIGUE ANALYSIS BY FEA APPROACH

First of all create a cad model of HUB AXLE in PRO-E software shown in fig 3

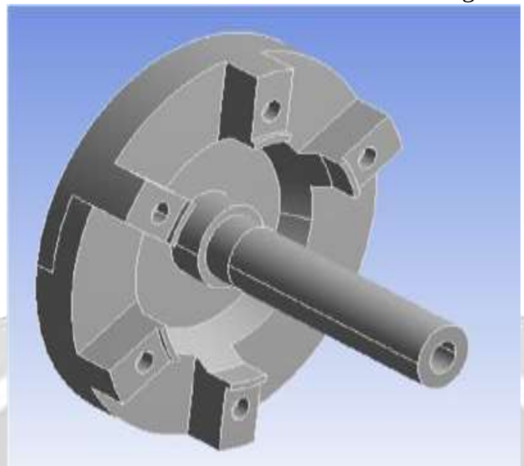

Figure.3 CAD model of hub axle

The PRO-E model of HUB AXLE is imported in ANSY WORKBENCH 14.5 software the loading condition of HUB AXLE shown in fig 4

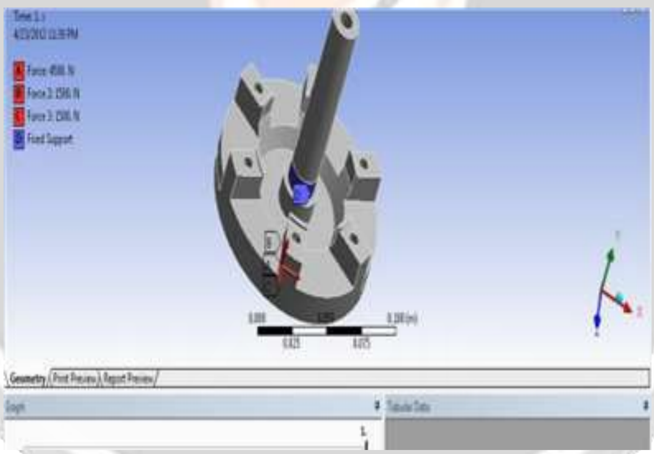

Figure 4.Loading condition of hub axle

Mashing the model of hub axle for that using (Element- tetrahedral, No. of node- 84500, No. of Elements- 49906)

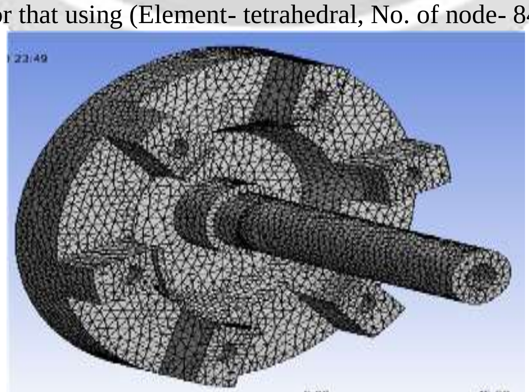

Figure 5.Mashing model of HUB AXLE

Von-mises stress of the vehicle axle shown in fig-6

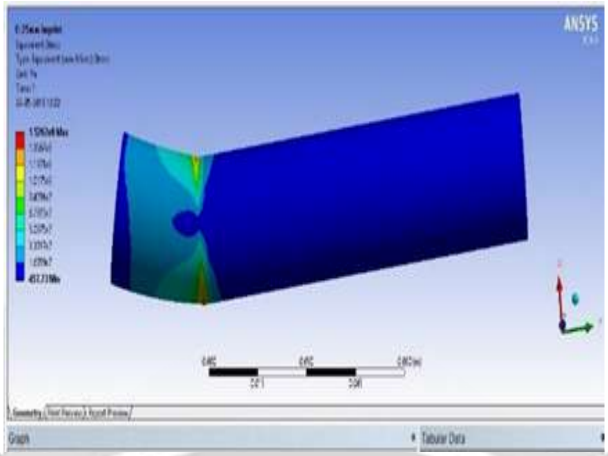

Figure 6. Equivalent / von-mises stresses of shaft

Fatigue factor of safety is shown in fig-7

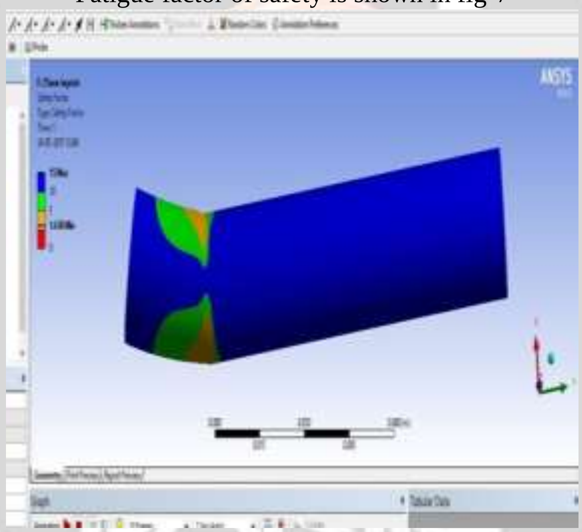

Figure 7. Fatigue factor of safety

Number of fatigue life cycle is shown in fig 8

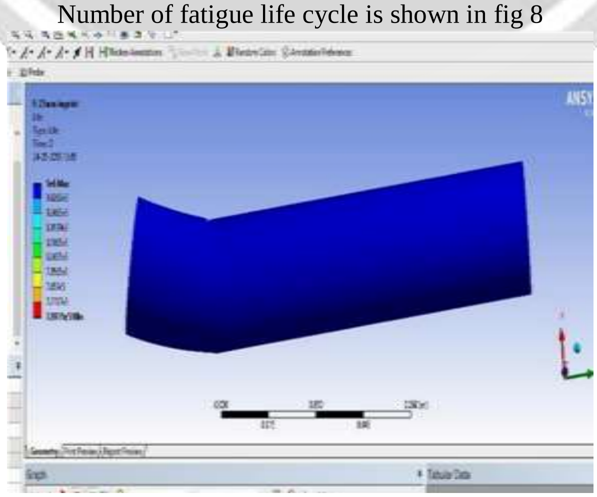

Figure 8. Number of fatigue life cycles

4. RESULT AND DISCUSSION

Table.2
Comparison of Analytical and FEA

Analytical approach	FEA approach
σeq=145.15 N/mm2	σeq=152.62 N/mm2
f.s=1.88	f.s=1.63
Infinite life	Infinite life

From above Table.2 it is clear that, the fatigue analysis of axle gives close results by Analytical and FEA approach. From optimization point of view the FEA analysis is very useful tool. Also, to change the material having low value of then to reduce the value of fatigue factor of safety up to 1.5 for saving cost of material. Software used for fatigue analysis ANSYS14.5 which gives moderate results. Loading condition applied for the axle is standard due to that result are varies if using more fine meshing results should be closer.

5. CONCLUSIONS

- The fatigue life prediction is performed based on finite element analysis and analytical method. Using the constant amplitude loading, the fatigue life of the axle has been predicted. This study will help to understand more the behavior of the axle and give information for the manufacturer to improve the fatigue life of the axle using FEA tools. It can help to reduce cost, critical speed and times in research and development of new product.
- It is clear from above results, Von-Mises stress value by analytical approach 145.15 N/mm2 which are nearly same by using FEA approach having difference of 10% in both results which is acceptable range. The fatigue factor of safety calculated from equation (9) is 1.88 & by FEA approach 1.63 again these values are approximately same. The number of life cycles are calculated by using modified Goodman method from S-N construction are 11.09 * cycles and by using FEA it will show safely run at 1* cycles. So, it will show infinite life cycle checked at High cycle fatigue.

6. REFERENCES

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