www.ijecs.in
International Journal Of Engineering And Computer Science ISSN: 2319-7242
Volume 5 Issues 7 July 2016, Page No. 17333-17337

Design and analysis of front axle for heavy commercial vehicle

Pravin R.Ahire[1], Prof.K. H. Munde[2]

[1]Anantrao Pawar college of Engineering and Research, Parvati Pune,
Maharashtra, India
ahirepravin23@gmail.com

[2] Anantrao Pawar college of Engineering and Research, Parvati Pune,
Maharashtra, India
kashinathmunde@gmail.com

Abstract: *Front axle carries the weight of front part of the Automobile, as well as facilitates steering and absorbs shocks due to road surface variations. The front axle is designed to transmit the weight of the Automobile front the spring to the front wheels, turning right and left as required. So proper design of front axle beam is extremely crucial. The paper deals with design and analysis of front axle. The same analysis with help of FE results were compared with analytical design. For which paper has been divided in to two steps. In the first step front axle was design by analytical method. For this vehicle specification – its gross weight, payload capacity, braking torque used for subject to matter to find the principle stresses & deflection in the beam has been used. In the second step front axle were modelled in CAD software & analysis in ANSYS software.*

Keywords: Front Axle, Design, Analysis, Automobile axle, construction and working of front axle beam.

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1. Introduction

An auto industry is one of the important and key sectors of the Indian economy. The auto industry includes of automobile sector, auto components sectors and includes commercial vehicles, passenger cars, multi-utility vehicles, two wheelers, three wheelers and related auto parts. The demands on the automobile designer increased and altered rapidly, first to meet system safety needs and later to reduce weight so as to satisfy fuel economy and vehicle performance requirements. Engine location important to provide greater stability and safety at high speeds by lowering the centre of gravity of the road vehicles; the complete centre portion of the axle is dropper.

Front axles are subjected to both bending and shear stresses. In the static condition, the axle might be considered as beam supported vertically upward at the ends (at the centers of the spring pads

Under the dynamic conditions, vertical bending moment is increased due to road roughness. Thus it is very difficult to find the crack propagation in short time. So it is necessary to incorporate finite element methodology. During the operation on vehicle, road surface irregularity causes cyclic fluctuation of stresses on the axle, which is the main load carrying member. Therefore it is necessary to make sure whether or not the axle resists against the fatigue failure for a predicted service life. Axle experiences completely different loads in different direction, primarily bending load or vertical beaming due to curb weight and payload, torsion, due to drive torque, cornering load and braking load.

Front axle will experience a 3G load condition when the vehicle goes on the bump. Performing physical test for vertical beaming fatigue load is expensive and time consuming. So there is a necessity for building FE models which may virtually simulate these loads and can predict the behavior. Even though the FEA produce fairly accurate results, solution accuracy heavily depends on accuracy of input conditions and overall modeling methodology used to represent the actual physics of problem. Therefore validation of FEA model is of utmost importance. Typically FEA model is validated by correlating FEA results

analytical design.

Hence correct design of the front axle beam is very critical. The approach in this paper has been divided into two steps. In the first step analytical method used to design front axle. For this, the vehicle specifications, its gross weight and payload capacity in order to find out the stresses and deflection within the beam has been used. In the second step front axle were modelled in Pro-e. The cad model was solved in ANSYS software system. The FE results were compared with analytical design.

2. Construction and Operation

2.1 Front axle

An axle is a central shaft used for rotating wheel. On wheeled vehicles, the axle could be mounted to the wheels, rotating with them, or located to its surroundings, with the wheels rotating around the axle. The axles achieve to transmit driving torque to the wheel. Also it can maintain the position of the wheels relative with each other and to the vehicle body. The axles must additionally bear the weight of the vehicle plus any cargo. The front axle beam is one of the main parts of vehicle suspension system shown in figure 1. It houses the steering assembly as well. About thirty 30-40 percentage of the total vehicle weight is taken up by front axle.

Front axle is made of I-section in the middle portion and circular or elliptical section at the ends.

DOI: 10.18535/ijecs/v5i7.27

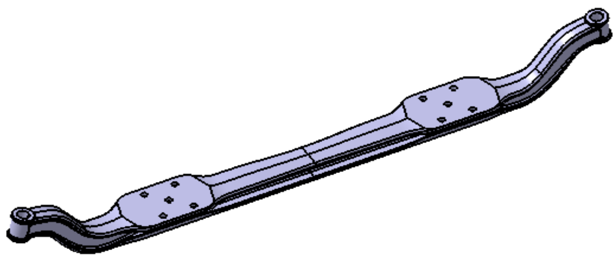

Figure 1: front axle beam

The special x-section of the axle makes it able to withstand bending loads due to weight of the vehicle and torque applied due to braking. It consists of main beam, stub axle, and swivel pin, etc. The wheels are mounted on stub axles.

The front axles are generally dead axles, but are live axles in small cars of compact designs and also in case of four-wheel drive.

2.2 Construction and Assembly

The front axle is generally a forged component for which a higher strength to weight ratio is desirable. The I cross section has lower section modulus and hence gives better performance with lower weight. This type of construction produces an axle that is lightweight and yet has great strength. The I-beam axle is shaped so that the centre part is several inches below the ends. This permits the body of the vehicle to be mounted lower than it could be if the axle were straight. A vehicle body that is closer to the road has a lower centre of gravity and holds the road better. On the top of the axle, the springs are mounted on flat, smooth surfaces or pads. The mounting surfaces are called spring seats and usually have five holes. The four holes on the outer edge of the mounting surface are for the U-bolts which hold the spring and axle together. The centre hole provides an anchor point for the centre bolt of the spring. The head of the centre bolt, seated in the centre hole in the mounting surface, ensures proper alignment of the axle with the vehicle frame.

The kingpin acts like the pin of a door hinge as it connects the steering knuckles to the ends of the axle I-beam. The kingpin passes through the upper arm of the knuckle yoke, through the end of the I-beam and a thrust bearing, and then through the lower arm of the knuckle yoke. The kingpin retaining bolt locks the pin in position. The ball-type thrust bearing is installed between the I-beam and lower arm of the knuckle yoke so that the end of the I-beam rests upon the bearing. This provides a ball bearing for the knuckle to pivot on as it supports the vehicle's weight. When the vehicle is not in motion, the only job that the axle has to do is hold the wheels in proper alignment and support part of the weight. When the vehicle goes into motion, the axle receives the twisting stresses of driving and braking. When the vehicle operator applies the brakes, the brake shoes are pressed against the moving wheel drum. When the brakes are applied suddenly, the axle twists against the springs and actually twists out of its normal upright position. In addition to twisting during braking, the front axle also moves up and down as the wheels move over rough surfaces. Steering controls and linkages provide the means of turning the steering knuckles to steer the vehicle. As the vehicle makes a turn while moving, a side thrust is received at the wheels and transferred to the axle and springs. These forces act on the axle from many different directions. Therefore, that the axle has to be quite rugged to keep all parts in proper alignment.

A hole is located in each end of the I-beam section. It is bored at a slight angle and provides a mounting point for the steering knuckle or kingpin. A small hole is drilled from front to rear at a right angle to the steering knuckle pinhole. It enters the larger kingpin hole very slightly. The kingpin retaining bolt is located in this hole and holds the kingpin in place in the axle. The steering knuckle is made with a yoke at one end and a spindle at the opposite end. Bronze bushings are pressed into the upper and lower arms of the yoke, through which the kingpin passes. These bushings provide replaceable bearing surfaces. A lubrication fitting and a drilled passage provide a method of forcing grease onto the bearing surfaces of the bronze bushings. The spindle is a highly machined, tapered, round shaft that has mounting surfaces for the inner and outer wheel bearings.

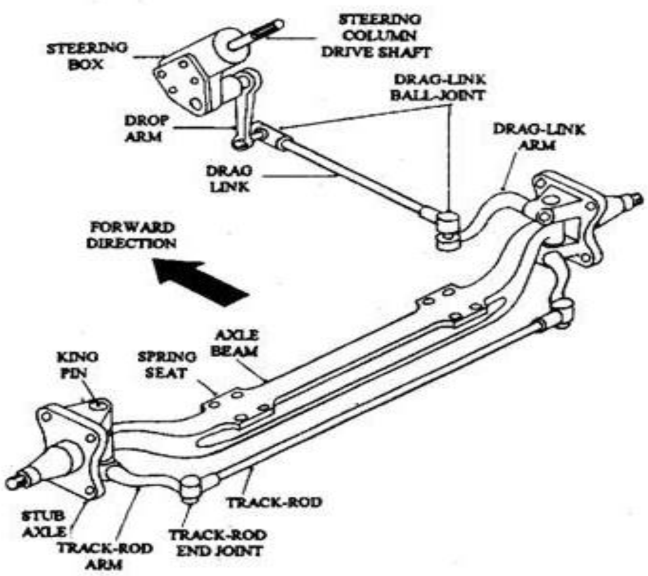

Figure 2: Front axle beam linkage assembly with Steering system

The outer end of the spindle is threaded. These threads are used for installing a nut to secure the wheel bearings in position. A flange is located between the spindle and yoke. It has drilled holes around its outer edge. This flange provides a mounting surface for the brake drum backing plate and brake components.

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3. Analytical Design

Analytical design need to find end solutions with helping system parameter inputs. The moment at section, bending stresses and principle stress is directly related to the strength. Now the above stresses are calculated by using following system input's and formula,

3.1 System Parameters

PARAMETER	UNIT	VALUE
FAW	Kg	3250
GVW	Kg	9500
Dynamic Radius (R)	mm	408
Front Track (Lt)	mm	1834
Distance of section (La)	mm	397.5
Wheel Base (L)	mm	4530
Unsprung mass of F.A. (Mfa)	mm	385.2
Weight of Wheel Rim + Tire + Tube (Wt)	Kg	110
Braking Torque/Wheel	Kg-mm	356592

Table 1: System Parameter table

3.2 I-Section Design

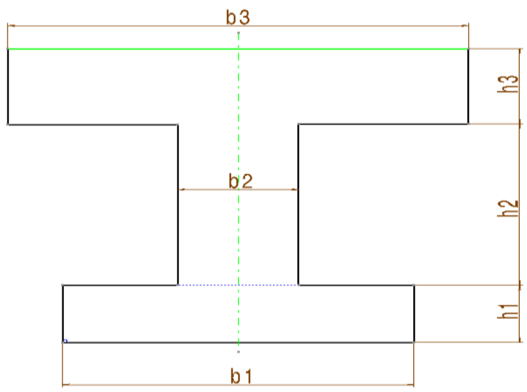

Figure 3: Axle I-section

Cross section of front axle beam is shown in Figure 3, for calculating bending stresses, tensional stress and principle stress value by considering I section dimensions, As b1= 68, b2=14, b3= 78, h1= 22, h2= 48, h3=22.

Moment at Section	M	1118602.55	Kg-mm
Max. Bending Stress	Fb max	20.2101	Kg//mm²
Total Bending Stress	Fb	25.5280	Kg/mm²
Torsional Stress	Fs	3.80367	Kg/mm²
Principle Stresses	Fp	26.08269	Kg/mm²

Table 2: Analytical Calculation Results

3.3 Deflection calculation along X- direction

In proposed design work consider material 27C15 for manufacturing front axle beam, material 27C15 having better for forging and having good impact load sustaining property. Below table shows some system parameters and modulus of elasticity of material 27C15.

Front Axle Weight	W	3500	Kg
Length (Kingpin center to spring pad center hole)	a	397.5	mm
Front Track	L	1834	mm
Modulus of Elasticity	E	2.1x10^4	N/mm²
Moment of Inertia	I	4178009.47	mm4

Table 3: System parameters table for deflection

As per system inputs calculation for deflection as,

Vertical deflection at spring pad

$$Yc=Wa^2 (3L-4a) / 6EI$$

$$Yc=7.845mm$$

Deflection at center of beam (max deflection)

$$Ymax=Wa (3L^2-4a^2) / 24EI$$

$$Yc=11.93 mm$$

3.4 Analytical Result

The value of principle stress for particular section is ~26.0826 Kg/mm². But Material Yield Limit for 27C15 is 72Kg/mm², for ductile cast iron material is for 37 Kg/mm².

From above calculation it has observed that 27C15 material deflection and the stress value is within material yield limit than ductile material, so same to be carry forward for design, manufacturing and scope for weight optimization.

Principle stresses calculated for 27C15 is below material Yield limit i.e. 72 Kg/mm² (ultimate tensile strength 78 kg/mm²). Hence the cross section has been optimizing.

4. Analysis for Front Axle Beam

ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. This computer simulation product provides finite elements to model behavior, and supports material models and equation solvers for a wide range of mechanical design problems

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4.1 Material Description

Mechanical (Physical) Properties

1) Poisson's Ratio (ϑ) : 0.3
2) Young's Modulus (E) : 193 N/mm2
3) Yield Stress (SYt) : 720 N/mm2
4) Tensile Ultimate Strength(σut) : 784 N/mm2
5) Density (ρ) : 8.08g/cm3
6) Elongation : 10% min

Chemical Properties

1) C: 0.22-0.32
2) Si: 0.10-0.35
3) Mn: 0.60-1.00
4) P: 0.050max
5) S: 0.050max

4.2 Finite Element Analysis

After application of boundary condition the model is solved. The load and deflection has been plot in anasys software module. The model of axle is simulated for material 27C15.

A) Maximum principle stress

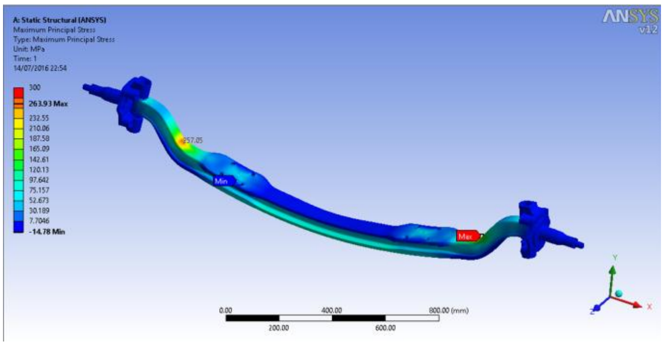

Figure 4: Analysis of Maximum Principle Stress

Above figure 10.3 shows results of Max principle stress in meshing, it is observed that the stress are produced on beam are 263.93 mpa which is below material yield limit (720mpa) and the same is acceptable.

B) Equivalent (Von-Mises) stress

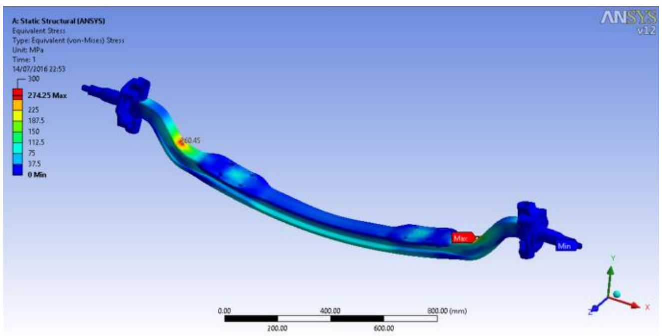

Figure 5: Analysis of equivalent (Von-mises) stress

Above figure 10.4 shows results of Max Von-mises stress in meshing, it is observed that the stress are produced on beam are 274.25 mpa which is below material yield limit (720mpa) and the same is acceptable.

C) Total Deformation

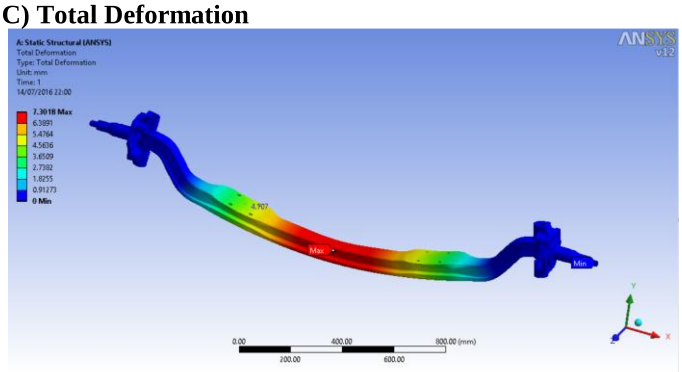

Figure 6: Analysis of total deformation

Above figure 10.5 shows results, it is observed that the Max Deflection at centre is 7.30 mm and at spring pad is 4.75 mm are produced on beam. Which is the comparatively equal with analytical deflection values and the same is acceptable.

5. Conclusion

From the above results shown, it is clear that the maximum deflection in front axle is 11.93 for 27C15 materials, so, that 27C15 is better material for manufacturing of axle. Also in the present paper we have established a satisfactory co relation between hand calculations done analytically and the FEA results. The deflection in the FEA gave the confidence that the boundary conditions for beam are correctly simulated. Correlation between stress results from analytical calculation and from FEA assures that the mesh size and modelling approach used for the component were well defined. Finally we were able to deliver a safe and validate design to suit the requirements.

6. Result

Stress distribution analysis of front axle was investigated by using finite element analysis. The model of the axle was developed by using CAD software. The dimension for front axle follow the real dimension based on the data collected. In order to run the simulation in the FE software, the model must be meshed. By using small values of the element size, the result given will more accurate. All the parameter and boundary condition for the front axle was defined in the FE analysis before run the simulation. In the analysis, in which the stress is distributed, stress concentration from the load given to the axle spring pad makes the axle failure. From the analysis, the result for stress distribution for equivalent von-Mises stress, normal stress, maximum principal stress, and Deflection of axle beam was analyzed and determined. From the several load given, the maximum load for the axle spring pads can stand was determined by using FE analysis. The result show that the maximum load can be carried by this front axle is 3500kg ≈ 35000N.

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