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OPTIMIZATION OF CAR STEERING SYSTEM TIE ROD BY USING EXPERIMENTAL AND FEA ANALYSIS

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Abstract – Tie rod is one of most important part of the steering system. It connects the center link to steering knuckle. This report represents the optimization of tie rod of a steering system of car using experimental and FEA analysis. The tie rod conventionally made of cast iron. In this dissertation work, the tie rod of SGI (Spheroidal Graphite Iron) material and Aluminium material have been casted. All three material's tie rods have been analyzed theoretically, experimentally and using Finite Element Analysis. The results have been compared with conventionally tie rod material by optimizing cost and weight. Theoretically stresses haven been calculated and are validated with the FEA stresses. Also using FEA total deformations and natural frequencies have been derived. The experimental analysis has been carried out using FFT by finding the natural frequencies at first mode. The results have proved that the optimization is possible by change in material with respect to reduction in weight and cost of the tie rod.

Key Words: Tie rod, FFT Analyzer, ANSYS.

1.INTRODUCTION

Tie rods connect the centre link to the steering knuckle on automobiles with conventional suspension systems and recirculating ball steering gears. On automobiles with MacPherson strut suspension and rack and-pinion steering gears, tie rods connect the end of the rack to the steering knuckle. Tie rods transmit force from the steering centre link or the rack gear to the steering knuckle, causing the wheels to turn. The outer tie rod end connects with an adjusting sleeve, which allows the length of the tie rod to be adjustable. This adjustment is used to set a vehicle's toes, a critical alignment angle, sometimes referred to as the caster and camber angles. A vehicle's steering and suspension systems should be checked regularly, at least once a year along with a complete wheel alignment. A worn tie rod end, due to rubbing and wearing, can cause wandering, steering and excessive tire wear. Tie rods may fail in many different ways, and except for a slight increase in noise level and vibration, there is often no indication of difficulty until total failure occurs. The general types of tie rod failure modes include fatigue, impact fracture, wear and stress rupture. The causes of tie rod end failure include poor design, incorrect assembly, overloads, inadvertent stress raisers or subsurface defects in critical areas, use of incorrect materials and/or manufacture process, and improper heat treatment.

2 LITERATURE REVIEW

Manik A. Patil et al [1] have discussed in their paper titled' "FEA of Tie Rod of Steering System of Car", that the most percentage weight of vehicle is taken by suspension system; however tie rod may get fail due to fluctuating forces during steering and bumping of vehicle . Vibration and fatigue of Tie rod has been continuously a concern which may lead to structural failure if the resulting vibration and stresses are severe and excessive. In their paper, Finite Element (FE) analysis of a typical tie rod of a car has been carried out and natural frequency has been determined.

Suraj Joshi et al [2] concluded from their work that in order to minimize the probability of shear and bending failure occurring in the engaged thread teeth on a steel tie rod in service, the number of engaged thread turns should be kept as low as possible. The trapezoidal threaded connection is strongly recommended in applications where the nominal diameter of the connection is greater than 80 mm (large-diameter steel tie rods).When the number of engaged turns is lower than eight, failure occurs at the engaged threaded connection in the form of shearing and then pulling out of the thread teeth in both the triangle and trapezoidal type thread connections.When the number of engaged turns is exactly eight, failure occurs at the middle part of unengaged thread (near the 16th turn) in the form of necking and then breaking of the cross-section of the tooth root on unengaged thread.

A.H. Falah et al [3] conducted study on a failed tie rod end of a SUV. Spectrum analysis and hardness measurement revealed that the failed part was AISI 8620 steel. The composition and hardness did not conform to the specified standard. Fractographic features indicated that fatigue was the main cause of failure of the tie rod end. On the fracture surface of the threaded part of the rod, the crack initiation region and beach marks could be clearly identified. It was observed that the fatigue crack originated from destructive areas in the vicinity of the throat and propagated from there. Failure analysis results indicate that the primary cause of failure of the tie rod was likely material deficiency. Formation of the crack initiation and propagation together with a final rupture within the fractured area supported this hypothesis and are, thus, in agreement with the claim of the SUV driver that the accident took place as a result of incompatible mechanical part, in this instance, the tie-rod end.

Sergio Lagomarsino, Chiara Calderini [4] studied the tensile axial force of metallic tie-rods in masonry arches and vaults. The identification procedure uses the first three modal frequencies of the tie-rod, measured by means of a dynamic test. The reference structural system consists of a beam with uniform section, subjected to an axial tensile force and spring-hinged at both ends. Besides the axial tensile force, the unknown variables are the bending stiffness of the section and the stiffness of the rotational springs. Since the characteristic equation of this structural system does not allow analytical solutions, the paper proposes an approximate numerical solution, based on a minimization procedure of a suitable error function. The robustness of the method is tested by identifying a number of ideal tie-rods, modelled by means of a FEM code.Moreover, since the homogeneity of the tie-rod's mechanical stiffness throughout its axis and the equality of the constraint conditions of its extremes are hypothesized, it is verified how such hypotheses may influence the tensile force estimation. Finally, the method is tested on real tie-rods.

Umesh S. Ghorpade et al [5] The automotive engine mounting systems are very important due to different aspects of vehicle performance. Early in improvement the building of the engine mounting system should be rapidly checked and precisely analyzed, without sample of a vehicle authorization. Engine bracket has been designed as a framework to support engine. Vibration and fatigue of engine bracket has been continuously a concern which may lead to structural failure if the resulting vibration and stresses are severe and excessive. It is a significant study which requires in-depth investigation to understand the structural characteristics and its dynamic behavior. This paper presents and focuses on some Finite Element (FE) analysis of a typical engine bracket of a car will be carried out and natural frequency will be determined.

George Campbell, Wen Ting [6] tested on a large scale finite element model of a tie rod in NASTRAN Version 68.The static buckling load of a tie rod is analyzed. The results of the finite element model are compared with experimental results. The analysis is performed in three steps. First, linear buckling is analyzed with SOL 105. Second, a nonlinear static analysis with arc length method is performed in SOL 106 to determine the instability behavior of the structure. In the last step, a nonlinear buckling analysis is done with restart into SOL 106 to determine the nonlinear buckling load. The tie rod has a strongly nonlinear behavior which is due to material yield and geometric nonlinear effects.

Michael Adam Kaiser [7] has made specific advancements in the technique to better align the stress and strain pulses using changes in slope instead of absolute time. He also worked on optimization technique for determining specimen diameter based on the impedance mismatch occurring at the interface of two materials. He worked on the technique for determining dispersive properties of longitudinal bars using existing Hopkinson bar apparatus.

PROBLEM STATEMENT

Based on the literature review and gap identification, the problem can be stated as "Optimization of car steering system tie rod by using experimental and FEA analysis with replacement of the existing material with best suitable material with low weight and low cost, keeping its functional properties constant".

Fig. No.2 Photograph of Tie Rod

3. METHODOLOGY

In this dissertation, the work has been carried out using FEA and experimental analysis for optimization of tie rod.

This dissertation work has been divided into following phases.

- *Phase I – Literature Survey*
- *Phase II – Study of various parameters*

The load acting on the tie rod of a steering system will be identified and critical parameters will be identified.

- *Phase III — Finite Element Analysis*

Modeling and Analysis of Tie rod is carried out by using CATIA and ANSYS. Also the Natural frequencies are obtained at critical locations by changing the material of Tie rod.

- *Phase IV Experimental analysis*

The Experimental analysis using FFT Analyzer been carried out in which the natural frequency at first mode has derived.

- *Phase V- Comparison of experimental and FEA results.*

The results obtained from experimental analysis and FEA has been compared and conclusions are drawn.

4. FINITE ELEMENT ANALYSIS

Finite Element Analysis is a mathematical representation of a physical system comprising a part/assembly (model), material properties, and applicable boundary conditions (collectively referred to as pre-processing), the solution of that mathematical representation (solving), and the study of results of that solution (post-processing). Simple shapes and simple problems can be, and often are, done by hand. Most real world parts and assemblies are far too complex to do accurately, let alone quickly, without use of a computer and appropriate analysis software. The numerical technique has advantages of experimental as well as analytical method. This analysis requires less resources compared to that of experimental methods.

The detail procedure consists of

a. Creating a model and Applying boundary conditions
b. Meshing.
c. Evaluating equivalent stresses
d. Evaluating total deformations.
e. Finding Natural frequencies at all 6 nodes.

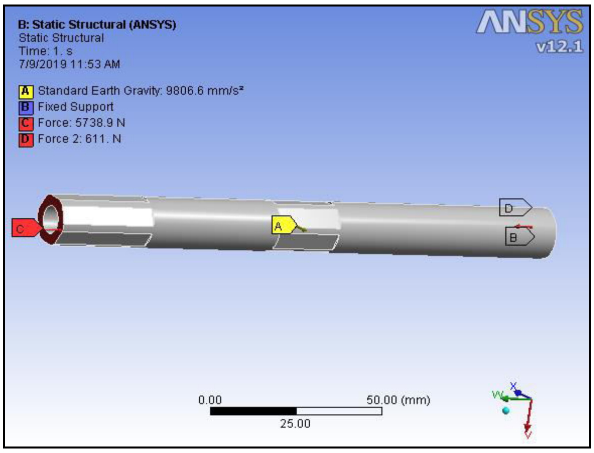

Fig.4.a Applying Boundary Conditions

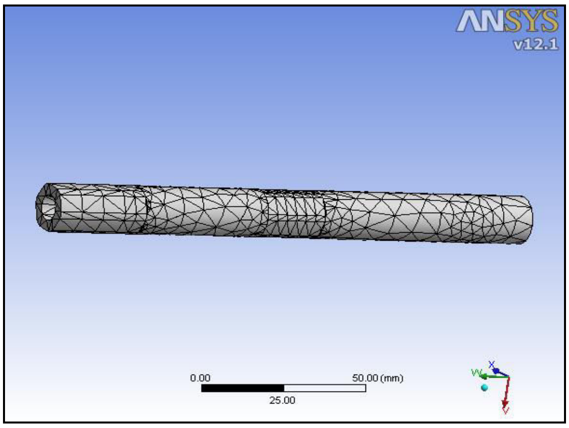

Fig.4.b Meshing

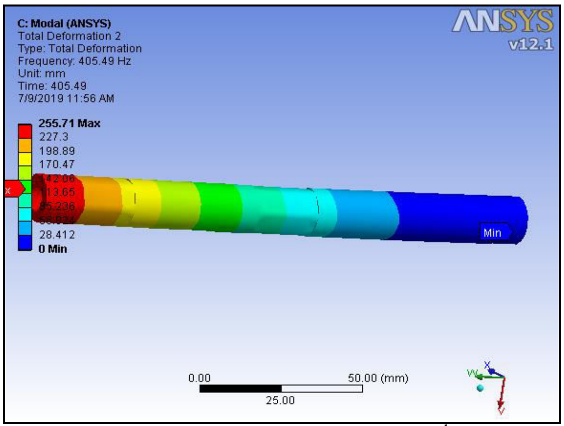

Fig.4.e (ii) Natural frequencies at 2nd node.

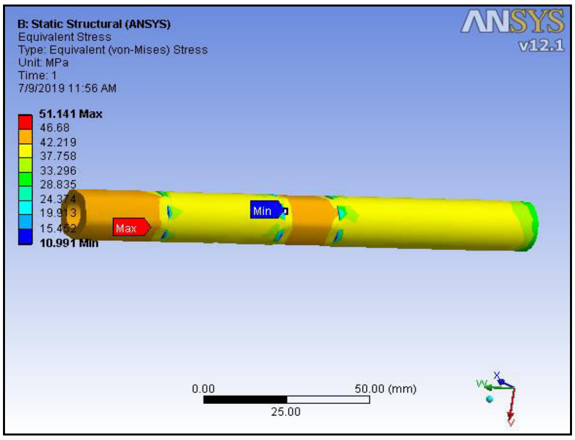

Fig.4.c Evaluating Equivalent Stresses

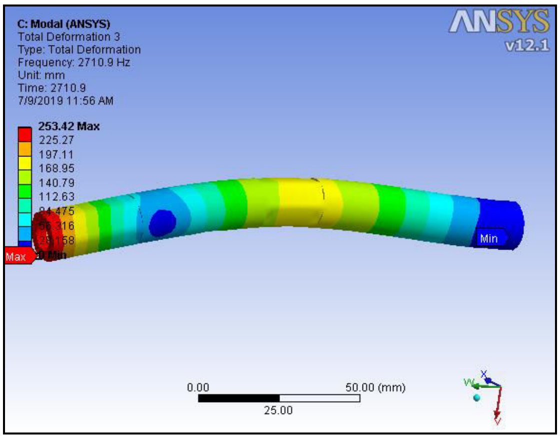

Fig.4.e (iii) Natural frequencies at 3rdnode

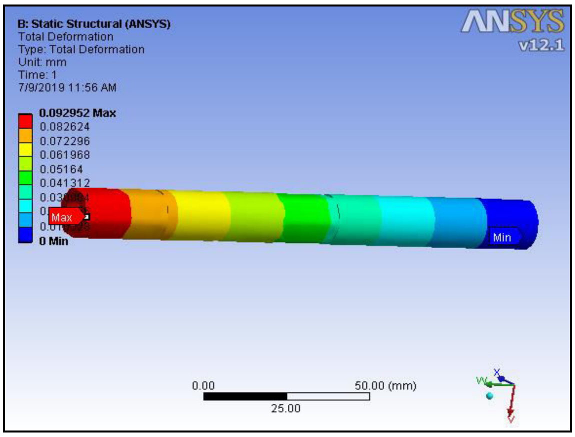

Fig.4.d Evaluating Total Deformations

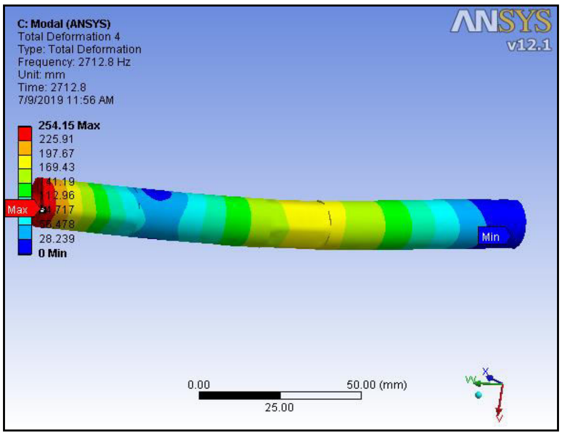

Fig.4.e (iv) Natural frequencies at 4th node

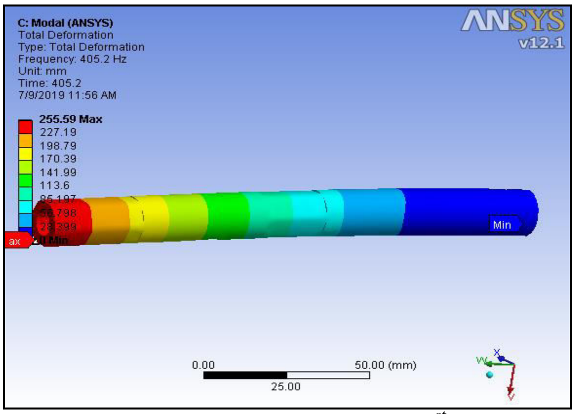

Fig.4.e (i) Natural frequencies at 1st node.

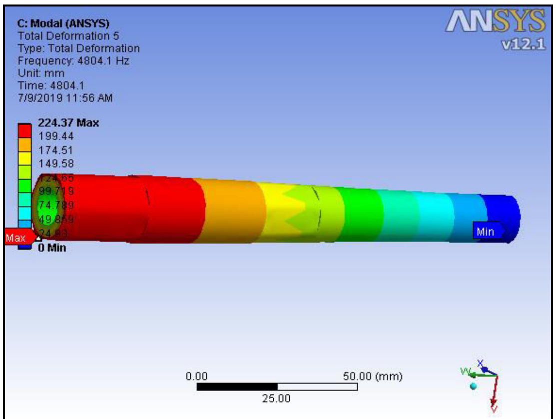

Fig.4.e (v) Natural frequencies at 5th node.

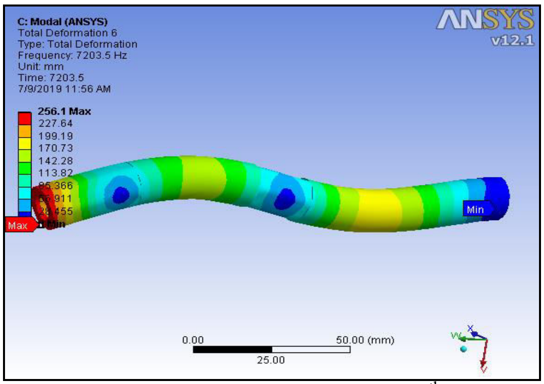

Fig.1. e (vi) Natural frequencies at 6th node.

4.1 RESULT OF FE ANALYSIS

Table No. 4.1 - FE Analysis of Tie Rods of All Materials

Material		Cast Iron	SGI	Aluminium
Equivalent(Von Misses)Stresses (MPa)		52.135	53.575	51.141
Total Deformation (mm)		0.060257	0.060283	0.092952
Modal Analysis (Hz)	M1	333.99	350.74	405.2
	M2	334.1	350.75	405.49
	M3	2112.9	2223.7	2710.9
	M4	2113.7	2223.9	2712.8
	M5	3780.9	4109.5	4804.1
	M6	5584.6	5892	7203.5

From the above table it is clear that the direct compressive stresses of Tie rod made of cast iron, SGI and aluminium are 52.135 MPa, 53.575 MPa and 51.141 MPa respectively. All the materials have equivalent stresses less than respective yield stresses i.e. 276 MPa for Cast Iron, 310 MPa for SGI and 230 MPa for aluminium. So the designs of all the three rods are safe.

5. EXPERIMENTAL ANALYSIS OF TIE ROD USING FFT ANALYZER

FFT is connected to laptop using USB cable. In this analysis we using 8 channel FFT. For modal analysis 2 adapters are connected to FFT. The accelerometer is connected to FFT using flexible wire and with the help of one adapter. Similarly Impact hammer is connected to FFT using flexible wire and with the help of another adapter. The magnetic base is attached to the accelerometer. The accelerometer is mounted on Tie rod and impact is given by using Impact hammer. The FFT hardware is connected to laptop having DEWEsoftX software. This software gives results in Digital format.

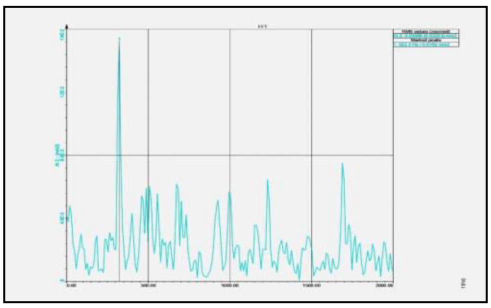

Figure 6(i) Modes of frequency of Cast Iron Tie rod

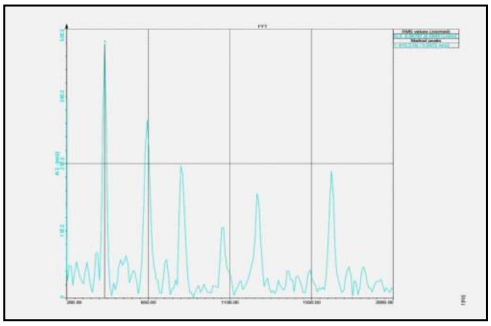

Figure 6 (ii) Modes of frequency of SGI Tie rods

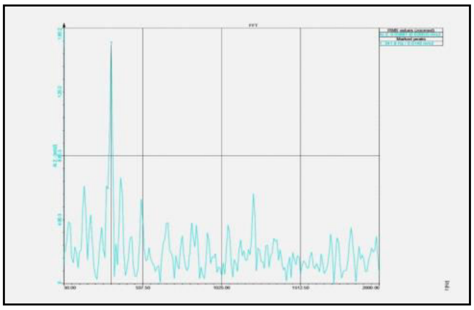

Figure 6 (iii) Modes of frequency of Aluminium Tie rod

6. RESULTS AND DISCUSSION

The use of low weight materials in the vehicle is main focus of Automobile manufacturers hence there arises a need to look to new material for use in their products. Some studies suggest that 4.5 to 6% fuel efficiency can be gained for every 10% reduction in vehicle weight. The typical aluminum cast Tie rod is lighter compare to Cast Iron and SGI material.

Table 7 *Comparison of Natural Frequency between FEA and Experimental Analysis Results*

Material	Natural Frequencies Using FE Analysis Hz	Natural Frequencies Using Experimental Analysis Hz	% Deviation
Cast Iron	333.99	323	0.96
SGI	350.74	341	0.97
Aluminium	405.2	410	0.98

It can be seen from the above results the values of frequencies are nearly same for all the three materials using FEA & Experimental Test. The deviation is about 0.96% for cast iron, 0.97% for SGI and 0.98% for Aluminium, which is acceptable.

7. CONCLUSION

In this dissertation, Optimization of Tie rod using Finite Element Approach and Experimental approach has been carried out by analyzing the vibration characteristics and by determining the natural frequencies.

- The analysis results shows that steel alloy, Aluminum alloy & Magnesium alloy are showing almost same value of Natural frequency.
- The aluminium material can be effectively used in replacement of Cast Iron and SGI.
- SGI shows almost same properties as that of Cast Iron.

- The values of cost and weight of aluminium Tie rod are much less as compared with Cast Iron and SGI.
- The aluminium can be best suitable alternative for tie rod material for its optimization.
- The finite Element Analysis approach is the best approach for analysis as the method has various in built functions and it is user friendly and accurate.

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