Design Optimization of Steering Rod and Performance of Structural Analysis

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***Abstract*— This Steering shaft/rod is an important part of overall steering system. It is a media between Steering wheel and steering box. However there are many issues related to its function-ability occurs. Stresses developed in an object, design requirements at the joints, deformation in body due to vibrations, continuous twisting and loading these are the common one related to steering rod. Since independent design parameters are defined for improving the performance of the steering system. In detailed design, occupant safety in a crash environment and vibration reduction is considered. Design optimization will provide us an additional way to nullify some of above issues. Improvement in design improves its working ability and its function-ability.**

Various Structural analyses (Static-Structural, Modal Analysis and Harmonic Analysis) of a steering rod will provide us external aids for improvements and optimization in design. Static-structural analysis is capable to find out deformation in body while model analysis is important in vibration point of view i.e. Vibrations in body can be calculated. Also Harmonic analysis will give us Natural frequency of body that to compare it with harmonic frequency.

Aim of this project is to perform design optimization of steering rod to nullify its function-ability issues related with stresses, deformation, vibrations, etc. Also suggest alternative way for nullifying problems and to minimize the cost by saving the material.

Keywords—Steering rod;Frequency; Optimization; Vibrations; Structural analysis; Modal analysis.

I. INTRODUCTION

The steering system of car is not only important for safety reasons but also to enhance the comfort of car's ride. The objective of this project is to design a steering rod which has same working capabilities as existing one by saving the material and find out vibration effects and behavior of rod at harmonic frequencies in an automotive steering system. This objective is worth pursuing because the issue of stresses developed in an object, design requirements at the joints, deformation in body due to vibrations, continuous twisting and loading these are the common one related to steering rod and is a real problem in the modern automotive industry.

It is near the top of the statistical list of most common steering failures. If and when undue steering motion occurs, the drivability of the vehicle decreases. Whether driving on back roads or on the freeway, the performance of the vehicle is noticeably reduced. It can also throw the front end out of alignment, which is hard on the wheel bearings, tires, and suspension. In a worst-case scenario, reducing vibrations can even reduce the risk of sudden catastrophic failure of major steering components. By improving the design and reducing the vibrations, the driving experience is thus safer and more precise.

The current steering system for most vehicles is the rack and pinion and power one, which uses a mechanical as well as hydraulic gearbox to steer the vehicle (Nice 2000). Axiomatic design has been used to form a design decomposition, to allow later designs to meet the functional requirements of this system.

II. PROBLEM DEFINATION

Steering shaft always undergo twisting movement while driving vehicle. Also the vibration in vehicles causes defects in its functioning ability. It is an important part of overall steering system. It is a media between Steering wheel and steering box.

Stresses developed in an object, design requirements at the joints, deformation in body due to vibrations, continuous twisting and loading these are the common one related to steering rod. Dynamic structural analysis will provide vibration effects on steering shaft/rod. Also its natural frequency domain can be calculated through Finite Element Analysis.

There is much scope in design of steering rod to minimize its defect due to twisting, vibrations etc. Optimization of design will provide better stability and less vibration defects in steering rod as well as column.

There are following types of causes which can create defects in a steering shaft.

A. Twisting Load

As steering column is a connecting media for steering wheel and steering box, it undergoes twisting load rapidly every time while driving of vehicle. This load is comparatively very small, as compare to strength of steering column. But at the point if Universal joint stresses can be developed which causes rod failure. Steering column failure will create huge problem about driver safety and control on vehicle. Therefore it is very necessary to avoid development of stress due to the loading and try to minimize it.

B. Vibrations while engine running condition

A vibration during engine running condition is a major issue for function ability of steering rod. Due to the vibrations in the steering column steering rod will vibrate and causes improper control on vehicle. Steering column and hence steering rod should be dynamically well balanced so that vibration in column does not affect control.

A vibration is also causes for stresses and deformation of steering shaft. Lesser the vibration, strength of steering rod hence column will be more.

C. Natural Frequency due to the vibrations

Due to the vibrations steering rod will produce a frequency at particular frequency band which is very important for resonance frequency point of view. If the natural frequency of a body steering rod will equate with its resonance frequency then it may collapse and suddenly driver's safety issues will occurs. By using model analysis and harmonic analysis one can calculate object natural frequency.

III. LITERATURE REVIEW

Tae Hee has study on the steering column and presented the paper as "Study on Steering Column Collapse Analysis Using Detailed Fe Model"

(Energy Absorbing Steering Column) is a kind of Steering Column which minimizes the injury of the driver during a car accident by collapse or breaking particular part of system. Up to now, Steering Column in Crash Analysis had no way to describe these 'Collapse' or 'Slip' by the Axial and Lateral Forces from driver. In this paper, they created a new Steering Column using a Detailed FE Model which can describe such collapse behavior. Here steering system is designed according to driver's safety. Steering shaft design is not disturbed.

Leslie Rayner (October 2004) has worked on Steering Design for a Formula SAE-A Open Wheel Race Car. The documentation includes a description of the design processes adopted for the various parts of the steering system. This begins with a review of currently used steering designs in modern motor vehicles and the projects design constraints. The next few chapters deal with the actual design of the steering components and their integration together. This is followed by the technical specifications of the final design and finally the conclusion. The steering system complies with all the relevant rules of the Formula SAE-A rule book. In this documentation steering system is more focused. Steering shaft is taken as available in market. Further research on steering rod is need.

Matthew Fulmer worked on Project of steering System the objective is to design three methods for reducing free play in an automotive steering system. Existing mechanical steering systems are flawed because they attempt to use interference to make up for the gradual onset of free play. The current system combines an increase in steering torque and a reduction in free play in a give-and-take fashion. This work attempts to work around that problem by coming up with several design solutions that should reduce the risk of free play. In this paper First design involves a pinion that uses rollers instead of gear teeth, in order to decrease friction. Second design eliminates the mechanical gearbox and uses hydraulics to steer the vehicle. A third design is similar to the previous one, but instead employs an electromechanical servo to operate the system. This documentation free play in steering system reducing methods has suggested. Free play in steering is controlled by optimizing steering rod design.

Above literatures have discussed about steering systems. But there are much scope in design of steering shaft and its optimization as a steering rod as no one yet seems to be worked on it.

IV. STEERING ROD MODELLING AND STRUCTURAL ANALYSIS.

A. Steering Rod

The shaft, in the steering column, which transmits the rotation imparted to the steering wheel by the operator to the steering device. The intermediate shaft is the shaft going to the driver side wheel from the coupling. The shaft is suppose to eliminate what you call torque steer. It comes straight from the coupling.

Fig. 1. Existing Steering Rod

This shaft undergoes twisting loads and vibrations. Due to this stresses will develop. Twisting movement while driving vehicle and the vibration in it causes defect in its functioning ability. Stresses developed in an object, design requirements at the joints, deformation in body due to vibrations, continuous twisting and loading these are the common one related to steering rod. Dynamic structural analysis will provide vibration effects on steering shaft/rod. Also we can calculate its natural frequency domain through Finite Element Analysis.

B. Cad Modelling Of Steering Rod

Various dimensions required to model steering rod are obtained by Reverse Engineering Process. Steering rod of Ford car is taken for modeling and analysis. Steel rule, Screw gauge, Micrometer, Vernier caliper etc. instruments are used for taking the dimensions from actual steering rods. CAD model of steering rod is prepared in such a way that it should exactly represent the actual steering rod virtually and its can be taken for the further analysis. Steering rod is modeled using Software Creo and the assembly is then converted into IGES file format i.e. neutral file to perform the analysis on steering rod it is imported in FEA software.

C. Optimization Process

Different Shapes for rod such as Square, Triangle Hexagon and Pentagon of different-different possible cross sections by which material could be save and results will be efficient some of them are as follows:-

1. Square
   Rod dimension Side = 17mm,
   Shaft dimension Side = 30mm

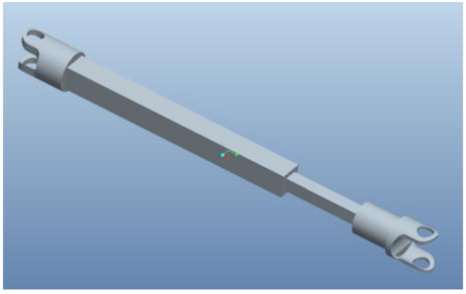

Fig. 2. Optimization as square type Steering Rod

2. Triangle
   Rod dimension side= 20mm
   Shaft dimension Side = 42mm

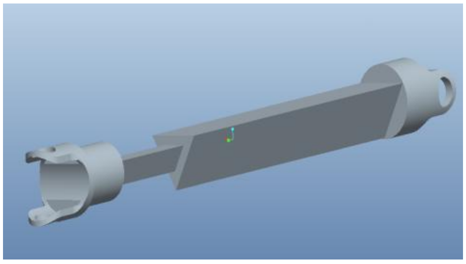

Fig. 3. Optimization as Triangle type Steering Rod

3. Pentagon
   Rod dimension side= 13mm
   Shaft dimension Side = 20mm

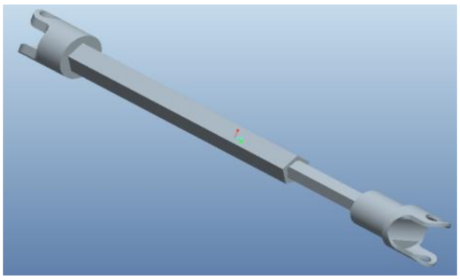

Fig. 4. Optimization as Pentagon type Steering Rod

4. Hexagon
   Rod dimension side= 12mm
   Shaft dimension Side = 18mm.

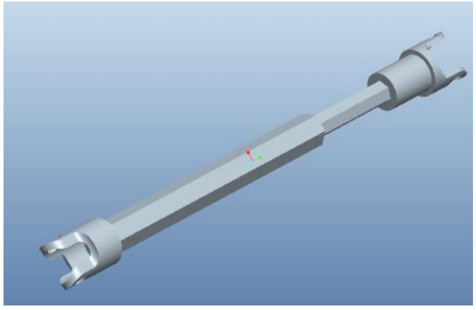

Fig. 5. Optimization as Hexagon type Steering Rod

From all above different cross sections the rod does not give the satisfactory results as that of the existing one in all analysis Structural, modal as well as Harmonic analysis.

Hence then by making dimensional changes to existing rod in some proportion to the design Variables I, get the better results.

D. Structural Analysis Of Existing And Optimised Steering Rod

Here first of all I am going to perform structural analysis of steering rod to find out effect of twisting load applied on rod. After importing CAD file into FEA tool I have to set analysis type as a Structural analysis. And type of element as 3D Tetrahedron element. Meshing of a steering rod is done with 3D tetrahedron element.

Mechanical properties of steering rod material
Where,
E= Young's Modulus = 220 GPA
ρ= Density = 7.6×10^{-6} Kg/mm^3
μ= Poisson's ratio = 0.28

By applying load and boundary conditions the maximum deformation and YZ shear Stress can be calculated in steering rod both in existing and optimised one.

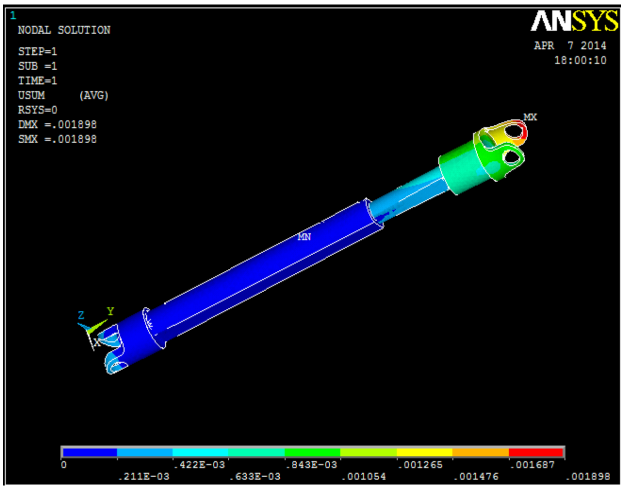

Fig. 6. Deformatin in Existing Steering rod.

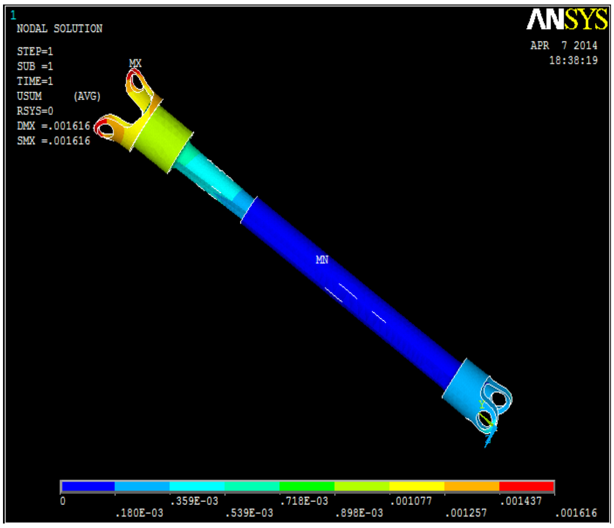

Fig. 7. Deformatin in Optimised Steering rod.

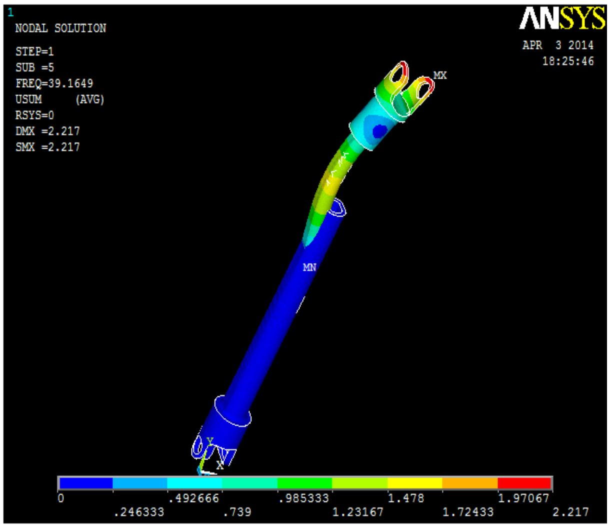

Fig. 9. Maximum Frequency Of Optimized Steering rod.

E. Modal Analysis Of Existing And Optimised Steering Rod

By applying load and boundary conditions the maximum deformation Use modal analysis to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic analysis, or a spectrum analysis.

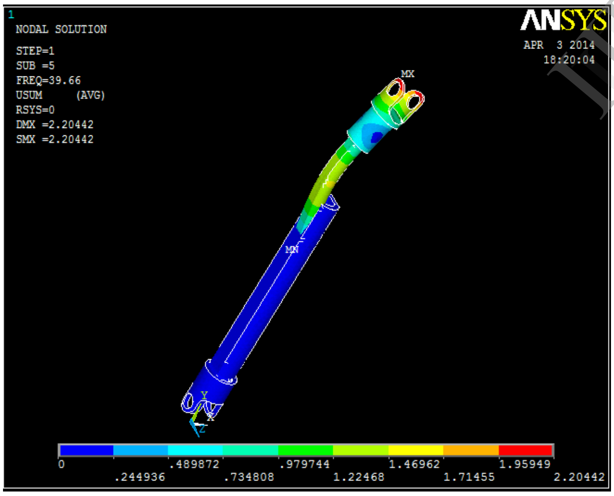

Fig. 8. Maximum Frequency Of Existing Steering rod.

F. Harmonic Analysis Of Existing And Optimised Steering Rod

Harmonic analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidal (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and Amplitude reviewed at those peak frequencies. This analysis technique calculates the steady-state, forced vibrations of a structure.

I have applied load on eight different nodes according to loading conditions on steering rod.

For eight nodes there are 8 graphs and all the graphs of all 8 nodes are nearly same below fig shows the graph of Frequency Vs Amplitude For one node of both existing and optimised one.

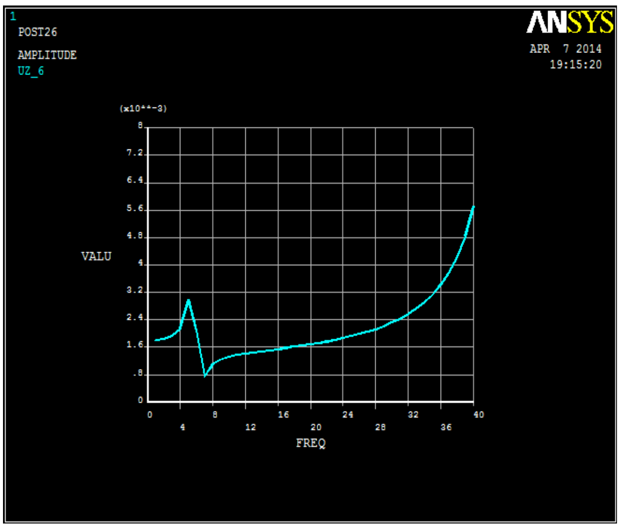

Fig. 10. Harmonic analysis of Existing Steering rod

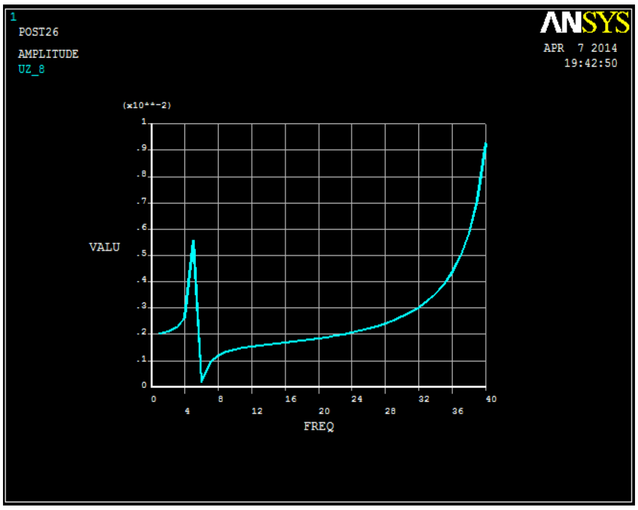

Fig. 11. Harmonic analysis of Optimized Steering rod

G. Analysis Result Validation

Validation is independent procedure that is used for checking that a product, service, or system meets requirements and Specifications and that it fulfills its intended purpose.

As because load applied at the end of rod and fixing from other end, I am able to find out possible deformation by analytical way

To perform vibration (Modal) analysis the principal equation is as follows.

$$([K] - \lambda[M])\{q\} = 0$$

Where,

$[K]$ = Stiffness Matrix.

$[M]$ = Consistent Mass Matrix.

λ= Eigen Values

$$\left(13.89 \times 10^{3} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} - \lambda \times 25.992 \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\right)\begin{Bmatrix} q1 \\ q2 \end{Bmatrix}$$

=0

λ=267.19 rad/ sec.

To convert above result into Hz above result must be multiply by 1/2π .

λ= 42.25 Hz.

The frequency value is approximately matched with vibration analysis value 39.66 Hz and 39.169 Hz. Hence the results obtained are valid.

V. RESULT AND DISCUSION

The Steering rod formation or assembly is made by assembling two parts rod and the shaft of both existing and optimised steering rod. The Assembly is converted into the neutral file format and this file is then used in Ansys for the analysis Purpose. Many other shapes such as Square, Triangular, Pentagon and Hexagon were tried for making the Optimization but all this shapes does not give the satisfactory results the optimization is made by making dimensional changes of the existing steering rod.

Bellow Table Shows the structural analysis results obtained in the ansys software of both existing and optimised steering rod. After this validation is done by the theoretical calculations using Fem method. In this combination of lumped mass and the consistent mass matrix is used to give the better results for frequency calculations.

TABLE I. RESULTS OF BOTH THEORETICAL AND SOFTWARE

Sr. No.	**Names of Analysis**	**Theoretical**	**Ansys Software**	
			Existing	**Optimization**
1.	Deformation	0.0021519 mm	0.001898 mm	0.001616 mm
2.	YZ Shear Stress	0.8332 N/mm^2	0.7162 N/mm^2	0.84993 N/mm^2
3.	Frequency	42.25 Hz	39.66 Hz	39.169 Hz
4.	Harmonic analysis		The Graph of both Existing and Optimised steering rod matches approximately	

Hence from the above discussion all the result values of the existing and the optimized and the theoretical calculations matches or are approximately same so the design of the optimized steering rod should be implemented.

By making volume calculations the volume of existing is 517.938 and volume of optimised is 463.62 hence the volume of optimised steering rod id reduced by 14%. Hence behind 7 rods by using optimised steering rod there can be one steering rod Hence quantities of steering rod production can be increased by 14%.

By mass calculation the mass is also reduced by 0.6 Kg. So it becomes lighter in Weight.

CONCLUSION

An Optimised design is the design in which cost is minimized. Here I made the dimensional changes to the design variables of the existing steering rod by setting the goal of design optimization which is to minimize objective function by selecting appropriate values of design variables.

In this objective functions are weight and Frequency is minimized by 0.6 Kg in optimized steering rod and the frequency of optimized steering rod is approximately same as that of the existing one. So design optimization of the steering rod is acceptable.

Hence the existing steering rod should be replaced by the optimized steering rod to minimize the cost by saving the material with same functionality as that of the existing steering rod.

FUTURE SCOPE

There is much scope in design of steering rod to minimize its defect due to twisting, vibrations etc. Optimization of design will provide better stability and less vibration defects in steering rod as well as column.

For making the rod better the rods ends should be made thicker where the coupling is to be used at the and were the universal joint used at the end. The material properties at both the ends should be made different and instead of circular cut at the ends it any other shapes should be tried for better results.

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