Design and Fabrication of Steering System for MPV-1

By

Muhammad Raza Tariq **NUST201201105**

Usama Javed **NUST201200881**

Supervised By

Engr. Mr. M Naweed Hassan

School of Mechanical and Manufacturing Engineering,

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

June, 2016

Design and Fabrication of Steering System for MPV-1

By

Muhammad Raza Tariq	**NUST201201105**
Usama Javed	**NUST201200881**

Supervised By

Engr. Mr. M Naweed Hassan

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelors of Engineering in Mechanical Engineering

School of Mechanical and Manufacturing Engineering,

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

June, 2016

FINAL YEAR PROJECT REPORT

We hereby recommend that the dissertation prepared under our supervision by: {Muhammad Raza Tariq (NUST201201105) and Usama Javed (NUST201200881)} Titled: {Design and Fabrication of Steering System for MPV-1} be accepted in partial fulfillment of the requirements for the award of Bachelors of Engineering in Mechanical Engineering degree with (_____ grade)

English and format checked by Ms. Aamna Hassan, Signature: __________________

Guidance Committee Members

1. Name: Lec. Sara Babar Signature: __________________

2. Name: Dr. Mohsin Jamil Signature: __________________

Supervisor's Name: Engr. Naveed Hassan Signature: __________________

Date: __________________

______________________ Head of Department

______________________ Date

COUNTERSIGNED

Date: ________________

______________________ Dean/Principal

Declaration

We certify that this research work titled "*Design and Fabrication of Steering System for MPV-1"* is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Muhammad Raza Tariq
NUST201201105

Usama Javed
NUST201200881

Copyright Statement

Dedicated to my parents

Acknowledgments

First of all I would thank ALLAH Almighty, who gave me knowledge and dedication to be able to complete this research.

We are grateful to Principal SMME **Dr. Abdul Ghafoor**, Vice Principal SMME **Engr. Muhammad Sohail** and H.O.D. Mechanical **Dr. Khalid Akhtar** for providing us the opportunity to work on the Final Year Project. We would also acknowledge all the support provided by School of Mechanical and Manufacturing Engineering (SMME) in completing the project.

We would pay our special tribute to **Engr. M. Naweed ul Hassan** for his continuous encouragement, invaluable supervision, timely suggestions and inspired guidance.

We are also grateful to **Lec. Sara Babar** and **Dr. Mohsin Jamil** for his motivating and useful remarks.

Mr. Usman Bhutta also worked hard in conducting evaluations and provided us with all the motivation required to complete the project.

Lastly I would like to pay my regards to the technicians of MRC especially **Mr. Farhad Khan**, **Mr. Faisal Nadeem, Mr. Mubashar**, **Mr. Hafiz Rizwan** and **Mr. Shoukat** who helped us throughout the fabrication phase.

Abstract

The deliverable of the project is to design and fabricate the Steering System for first prototype of Multi-Purpose Vehicle (i.e. MPV-1). The task also included the selection of the best type of steering system for this particular Multi-purpose vehicle. The Deliverables also included the recommendations about which parts in the steering system we would be able to pick off the shelf and what parts we would have to make ourselves for this particular type of vehicle. Main purpose of the car is to fulfill the requirement of being low cost vehicle that can be used by families to travel within the vicinity of their locality. The basic aim was to design a steering system that was economical and easy to manufacture locally. Different types of steering systems were studied and ultimately Rack and Pinion steering system (Ackerman steering) was chosen for Multi-Purpose Vehicle 1. The reason behind choosing Ladder Rack and Pinion steering system was that it was simple and could be fabricated in Manufacturing Resource Centre (MRC), SMME. The steering system was modelled in Solid Works and stress analysis was done. After the analysis, we surveyed the market and chose a steering system that was close to our design and then modified it in MRC. We used the facilities of Manufacturing Resource Centre (SMME) to fabricate and mount different components of Steering System.

Table of Contents

Symbols

AL2024 T3	Aluminium Alloy 2024 heat treated
F	Load
t, t_1, t_2	Adherend thicknesses
t_a	Adhesive thickness
$\varepsilon, \varepsilon_{x1}, \varepsilon_{x2}$	Longitudinal strains
τ	Shear stress
G	Modulus of rigidity of adhesive
E_1, E_2	Modulus of elasticity for plates
E_a	Modulus of elasticity for adhesive
l	Length of overlap
b	Width of overlap
A, B	Constants of solution of differential equation
τ_m	Mean tangential stress
τ_n,	Destructive stress
M	Bending moment
E_{Total}	Total strain energy
σ	Tensile stress
$\sigma_{p(max)}$	Max peel stress
$d\Omega$	Structural domain

Chapter 1
Introduction

1.1 Background

In this era of cutting edge competition world is thinking of making products that can fulfill more than one specific purpose. Moreover a shift can be observed from heavy weight products towards manufacture of light weight and efficient products, without having any compromise on the reliability. Hence, there incepts an idea of making a light weight car that can fulfill more than one purposes with a few replaceable parts. The Vehicle was named as Multi-Purpose Vehicle its first prototype was called as MPV-1 NUST-SMME is part of a consortium to build Multi-Purpose Vehicle along with 4 other universities; namely UET Lahore, CUST, NED and COMSATS. The main advantage of Multi-Purpose Vehicle is that, it will have same chassis but the upper cabin will be easily replaceable to fulfill the design variants.

1.2 Aim and Objectives

The aim of this project is to incept the idea of low cost Multi-Purpose Vehicle by designing and fabricating the steering system for the initial prototype of MPV-1 and that is essentially targeted to meet the day to day requirement of small lower/middle class families for mobility within their residential bounds.

Main purpose is to check the fitment of off the shelf parts of steering system and recommend if each part may be used with slight or without modification or redesign of the part is required. The following objectives were identified in order to achieve the overall aim of this research.

- Steering system we chose was rack and pinion type.
- Off the shelf parts will be used to keep the design and manufacturing cost low.
- Parameters of the prototype will be same as of the original Multi-Purpose Vehicle.
- Off the shelf parts will be modified to some extent.
- Redesign will be recommended for the parts that do not fit properly on the chassis.

1.3 Research Methodology

The schematic of overall methodology that was followed during the project is shown in Figure 1.1.

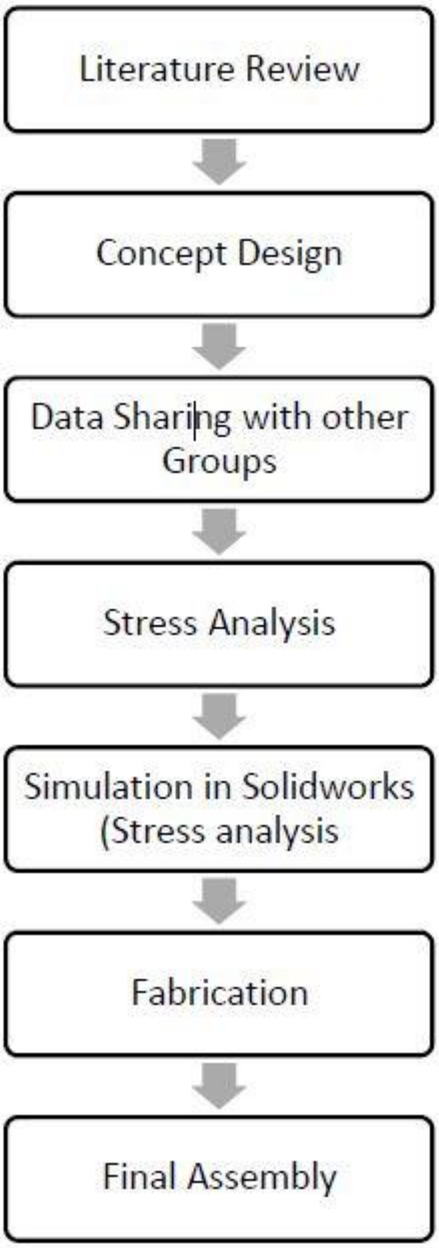

Figure 1.1: Overall Schematic of Research Methodology

1.4 Thesis Structure

The brief description of the contents of the remaining chapters in thesis is described below.

Chapter 2
Literature Review

This chapter provides a summary of the literature that has been reviewed and identified to be relevant to this project. Description of different types of steering systems with their advantages and disadvantages are also discussed in this chapter.

2.1 Types of Steering Systems

Following are explained, different types of Chassis along with their merits and demerits:

1. Rack and pinion

2. Recirculating ball

3. Worm and sector

Rack and Pinion

Many modern cars use rack and pinion steering mechanisms, where the steering wheel turns the pinion gear; the pinion moves the rack, which is a linear gear that meshes with the pinion, converting circular motion into linear motion along the transverse axis of the car (side to side motion).

- This motion applies steering torque to the swivel pin ball joints that replaced previously used kingpins of the stub axle of the steered wheels via tie rods and a short lever arm called the steering arm.
- The rack and pinion design has the advantages of a large degree of feedback and direct steering "feel". A disadvantage is that it is not adjustable, so that when it does wear and develop lash, the only cure is replacement.

Recirculating Ball

The recirculating ball version of this apparatus reduces the considerable friction by placing large ball bearings between the screw and the nut; at either end of the apparatus the balls exit from between the two pieces into a channel internal to the box which connects them with the other end of the apparatus, thus they are "recirculated".

- The recirculating ball mechanism has the advantage of a much greater mechanical advantage, so that it was found on larger, heavier vehicles while the rack and pinion was originally limited to smaller and lighter ones; due to the almost universal adoption of power steering, however, this is no longer an important advantage, leading to the increasing use of rack and pinion on newer cars.
- The recirculating ball design also has a perceptible lash, or "dead spot" on center, where a minute turn of the steering wheel in either direction does not move the steering apparatus; this is easily adjustable via a screw on the end of the steering box to account for wear, but it cannot be entirely eliminated because it will create excessive internal forces at other positions and the mechanism will wear very rapidly. This design is still in use in trucks and other large vehicles, where rapidity of steering and direct feel are less important than robustness, maintainability, and mechanical advantage.

Worm and Sector

This type of steering gear looks a lot like our bolt and nut, but the sector of this type looks like a gear instead of a nut. The teeth of the sector are machined in an arc, or curve, so that they actually look like a section of a gear. As the steering wheel and worm turn, the worm pivots the sector and pitman arm shaft. The sector pivots through an arc of 70 because it is stopped at each extreme when it touches the steering gear housing.

- The worm is assembled between bearings, and some means is provided to adjust the bearings to control worm end play. The pitman arm shaft is fitted into the steering gear housing on bearings (generally the bushing type, but roller type bearings are sometimes used).
- A lash adjustment screw is also provided so that the sector can be moved closer to, or farther away from, the worm gear to control the backlash between the sector and worm threads or teeth.

2.2 Choosing the Best Steering System for MPV-1

To understand why we selected a particular steering system, there were certain features/specifications about the vehicle that helped us reach at a decision. These were:

- The vehicle was being designed for the middle and lower middle class families of Pakistan. So, the cost of the vehicle was a major deciding factor.

- The vehicle was intended to have low to mid-range specifications with a top speed of just 80 km/h.
- It was required to make the vehicle as simple as possible for the following reasons:
    - ✓ to bring down the costs of manufacturing
    - ✓ to be able to fully manufacture the vehicle in Pakistan
    - ✓ to have extremely low maintenance costs

In the light of above all requirements, our research narrowed down to Rack and pinion type steering system. It checked almost all of our requirements and specifications that we wanted our steering system to have.

Chapter 3
Calculations and 3D Modeling

3.1 Introduction:

Initial calculations were performed to choose the best steering system for the MPV-1. Based on these calculations a steering system was picked off the shelves from the market and the calculations were then again performed on the picked steering system to be sure that it is suitable and safe for use for MPV-1. The 3D model of the steering system was made using the commercially available software, Solidworks, which is developed by Dassault Systemes, Providence, RI, USA.

3.2 Initial Calculations:

In the initial calculations we did calculations to find out the appropriate length of rack and pinion teeth. The calculations we performed are mentioned below:

We performed several iterative calculations by putting values of rack size, pitch and pinion teeth that would be suitable for our particular needs. The final values which gave us the safe readings when rack size was 137mm with a pitch of 4.5mm and with a pinion having 5 teeth.

Radius of Steering Wheel = R = 155mm

Steering Ratio = Xi/Xo = 2(pi)R/2(pi)r

Xo = 39mm (output Rack Movement)

Radius of pinion = r = Xo/2(pi)

r = 6.2mm

Ackermann geometry angle

$R1 = B/\tan\theta i + L/2$ & $1/\tan\theta o = 1/\tan\theta i + L/B$

The values came out to be:

$\theta i = 23.58^o$ & $\theta o = 19.06^o$

Next, we calculated the **Steering ratio** using the formula:

R = S / [2-2cos(2a/n)]1/2

The answer came out to be n = 25:1

The **rack movement Xo per revolution** were calculated as

Xi / Xo = 2(pi)R/2(pi)r

The Force to turn the wheels:

Weight of Car = 750kg

40% of car weight is on front Wheel Assembly

So,

Effective Weight = 750 x 0.40 = 300kg

Weight on each wheel = 150kg = 150x9.8 = 1470N

FR = μ*N = 1x1470 = 1470 N = FL

Torque on pinion = F * r = 1470 x 6.2 = 9114 Nmm

Force required to steer the Steering Wheel = T / R steering wheel = 60 N

The global standard for the appropriate amount of force required to turn the steering wheel lies between 20-100N.

Torsion Effect on Steering Column

D = 18mm   d = 16 mm

Tmax = T*R/J

= 42.3 MPa

SAE 1015 Steel can withstand maximum of 386.1 MPa. So, our calculations are safe.

As, our calculations were in the safe limits so we decided to use these configurations in our steering system.

3.3 3D Modelling:

Based on these calculations the 3D model of the steering system was developed using Solidworks which is developed by Dassault Systemes, Providence, RI, USA. The screenshot of the 3D model is shown in fig (3.1).

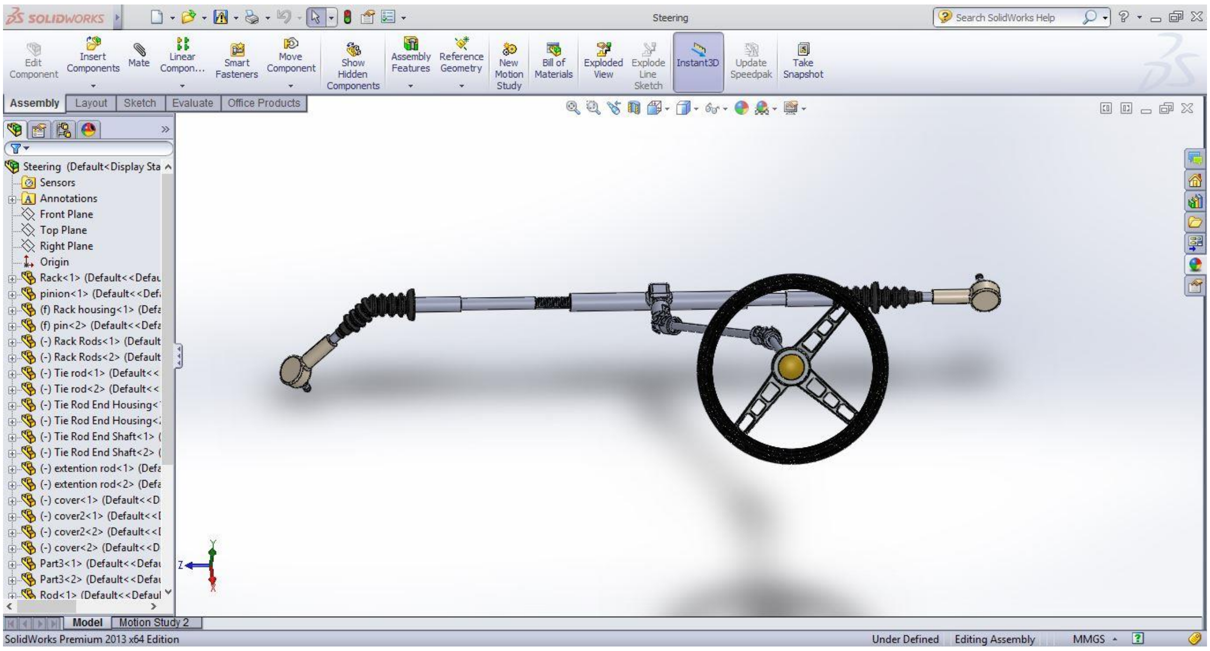

Fig. (3.1) Screenshot of the 3D model

3.4 Final Calculations:

Based on the initial calculations, a suitable steering system was picked off the shelf with the measurements closest to the initial calculations. Calculations were then again performed on the chosen steering system just to be sure of its safety and suitability for MPV1. These calculations were:

The **rack movement Xo per revolution** is calculated as

Xi / Xo = 2(pi)R/2(pi)r

Xo = 35mm

The **Force to turn the wheels** is calculated as:

Weight of Car = 750kg

40% of car weight is on front Wheel Assembly

So,

Effective Weight = 750 x 0.40 = 300kg

Weight on each wheel = 150kg = 150x9.8 = 1470N

FR = μ*N = 1x1470 = 1470 N = FL

Torque on pinion = F * r = 1470 x 5.57 = 8187.9 Nmm

Force required to steer the Steering Wheel = T / R steering wheel = 43.67 N

It is advisable to keep the force required to steer the wheel below than 100 N for a smooth steering experience. Clearly our force is within the limits.

We calculated the **torsion effects** in the column using this formula:

Tmax = T*R/J

where for Solid Cylinder

$$J_z = \frac{\pi D^4}{32}$$

where D = 17.45mm

So, J = 9098.32 mm4

Putting the values, we get

Tmax = 168 MPa

SAE 1015 Steel can withstand max of 386.1 MPa, so our design was safe.

Chapter 4

Results and Discussion

4.1 Results and Discussion:

The calculations performed on the chosen steering system were pretty close to the initial calculations. The rack length of the chosen system was 135mm with a pitch of 5.85mm and a pinion diameter of 5.85mm. Force to turn the wheel of the selected system is 43.67, which is in the limits of globally accepted range (below 200N). The torque producing in the steering column of the selected steering system was calculated to be 168MPa which is safe in the safe limits for SAE 1015 steel which has an upper limit of 368.1 MPa. The tie rod lengths were a little more than we needed, so we customized them according to our particular needs.

Chapter 5

Conclusions and future work

5.1 Achievements:

For MPV-1 off the shelf parts were used and modified whenever needed. After using engineering knowledge and calculations we selected the suitable steering system and installed it in the vehicle to physically test and validate our findings. We customized and adjusted the tie rod lengths according to the tread of the vehicle. We found out the steering system we selected was suitable for MPV1 vehicle with just a little customization needed. We collaborated with the chassis team to correctly install the steering system in the vehicle.

5.2 Future Work:

We manufactured Multi-Purpose Vehicle's first prototype (MPV-1). The cabin of MPV-1 is to be built. Seats are to be installed on the frame. The proper transmission from engine to wheels has to be done. Electronics of the Vehicle needs to be installed. Proper assembly of accessories on dash board and on other various part of vehicle is to be done.

References

- Automobile Engineering by *R. K. Singal*
- Fundamentals of Vehicle Dynamics by *Thomas D. Gillespie*
- Research Paper on Virtual Prototype of Rack and Pinion Steering Gear Meshing by *Naresh Kamble & Rajesh Priyadarshi.*
- A Text Book on Automobile Chassis and Body Engineering by *Sri. N.R.HEMA KUMAR.*
- Atlanta Servo Catalogues 2013
- Simulation and optimization of the steering kickback performance by *Marek Szczotka.*
- Developing a Virtual Prototype of a Rack and Pinion Steering System by *Naresh Kamble and S.K. Saha.*
- Materials Science and Engineering: An Introduction by *W.D. Callister, Jr., John Wiley and Sons, Inc.*
- Fundamentals of Modern Manufacturing processes by *Mikell Groover.*
- Mechanical Engineering Design by *Shigley.*