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# Variable gear ratio rack and pinion spur gear for steering system

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**A B S T R A C T :** In accordance with the present invention, there is provided a novel and improved variable ratio rack and pinion steering gear where in the pinion has teeth of variable shape and size and the rack has teeth of variable shape and size. The teeth of the pinion are correctly meshable with a uniformly shaped rack profile and adopted to provide variable pitch lines. The teeth of the rack are generated by using the profile of the pinion teeth.



**Keywords:** Invention, Variable ratio, Gear ratio, Meshable

## 1. Introduction

We are belongs to team OJASWAT which designs and manufactures formula-3 racing cars for the event organized by society of automotive engineers. During the working on that particular project, we take the responsibility of steering system. As a part of it during the calculation time we observe that there is a decrease in force required to turn the wheels we are going to increase the module of the same gear. So we thought that why can't we manufacture more than one module of teeth on a single pinion gear and similar on the rack gear. So as a part of it, we have done lots of brain storming, internet surfing, referring articles, taking advise from the our faculty advisor on it. Because as we know that any two gears can only transmit power efficiently when they meshing to each other on pitchline.so we get to know that there is some eccentricity we have to provide on pinion radius on the lesser module side, so that we can maintain the continuous pitch-line & similar we have to design on a rack gear. We have also referred some articles of foreign author articles as given in references. So by looking more into the topic we get to know that as higher the module we providing on a rack, the effort required for linear movement of the same gets decrease and the efficiency of power transmission gets increase. Now, steering wheel rotation and number of variable module are also depends on each other. As, we are having more than one revolution of steering wheel (lock-to-lock) in our day-to-day life vehicle, we can provide more than two no. of module on each (Rack and pinion).But according to our project requirement we are having limited angular rotation of steering wheel (around 180º).therefore we have design our rack and pinion component by considering two module (M=1.5& 2.0) only. there is also a calculation done for (1)force requirement (2)Stress to be generated(3) cross-check of module based on Uniform wear theory. There is also attached a photocopy of design and analysis of variable rack and pinion.

## 2. Advantages of variable gear ratio steering system over the simple steering system

Many attempts have been made to incorporate the principle of ratio variation into the popular rack and pinion type steering gears for small cars, but certain limitations have prevented them from being accepted. One

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method which has been tried is to provide a pinion with variable pitch radius and a rack with varying height teeth to match. Such a gear is limited to about 1.8 turns of the steering wheel to steer the vehicle from lock-to-lock. This has been rejected as undesirably fast steering. An attempt to remedy this has been made by introducing a pair of reduction gears ahead of the deformed pinion. The added cost has made this compromise undesirable. In addition, the amount of ratio change available has been somewhat limited by problems of design and manufacture of the deformed gears.

- Due to higher module present at the center of rack, it requires very low angular rotation of steering wheel to turn the vehicle.
- It is an object of this invention to provide a variable ratio gear which permits the vehicle designer to select any number of turns of the steering wheel to steer from lock-to-lock as he wishes.
- Another object of this invention is to provide a variable ratio steering gear using conventional gears made on ordinary machines with standard tools, whereby the cost increase to provide the variable ratio feature is held to a minimum
- Still another object of the invention is to provide a variable ratio steering gear in which the designer, having selected the effective average ratio by determining the number of steering wheel turns for steering from lock-to-lock, also is free to select from a wide range the effective peak ratio at the center and the effective minimum ratio at the locks

## 3. Detailed description of design

When we have started to design above variable rack and pinion, then at we faced to many problems related to design like (i) how to generate involute profile of a teeth (ii) how to arrange teethes of different module on a single pitch circle (iii) spacing between the teeth of module 1.5 & 2.0 (iv) Meshing errors, etc. While we are facing above mentioned problems, we have done lots of communication with our faculty advisor and also with a teammates, we also refers many gear design tutorials related to it and then again we have started with the designing and at the 1st attempt of design we had got an error of around 3 mm and then by re-arranging the relative positions of the different module gears we have optimized it up to the 0.738 mm which again we can say this is very negligible error so we can neglect it during the manufacturing of the same. As shown in fig. performance of the steering system also gets vary as we did variation in angular rotational limit of steering wheel. From figure 1, it is clear that rotation of steering wheel about the 180° gives the best outcome, so that we will do the same with our FSI 17 car.

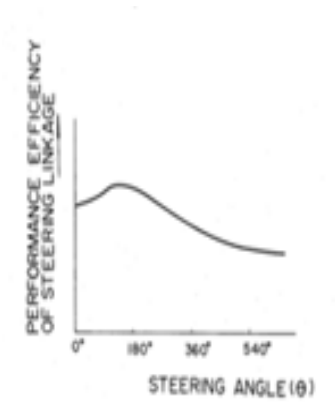


Figure 1 Efficiency vs steering angle graph

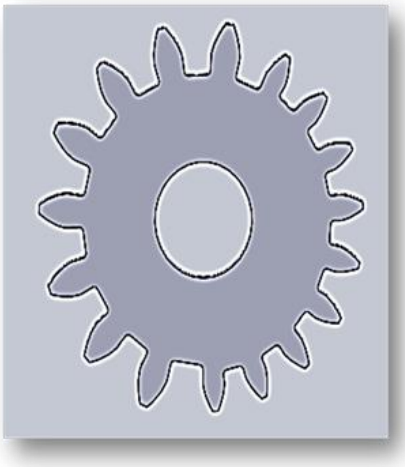

Figure 2 Cad Model of Pinion Gear

Figure 3 Cad Model of Pinion Gear

## 4. Cad Models of Design and Analysis

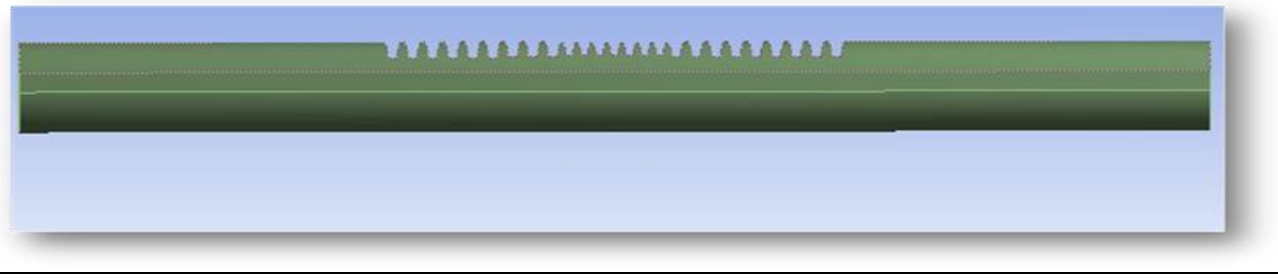

Figure 4 Cad Model of Rack Gear

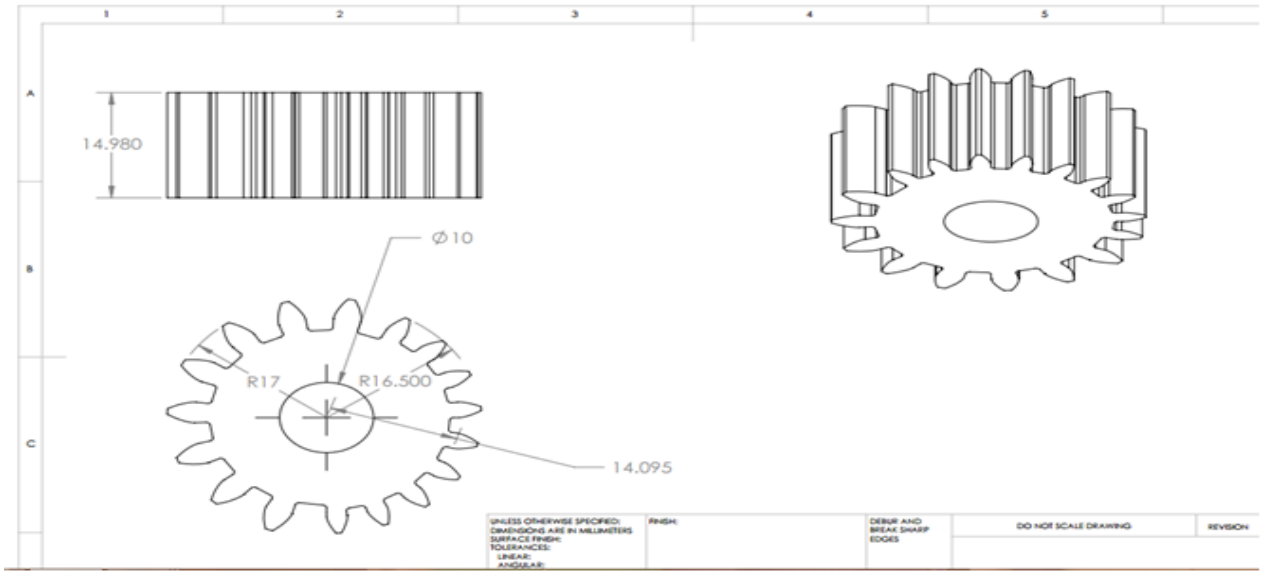


Figure 5 Isometric view and 2D view of pinion gear

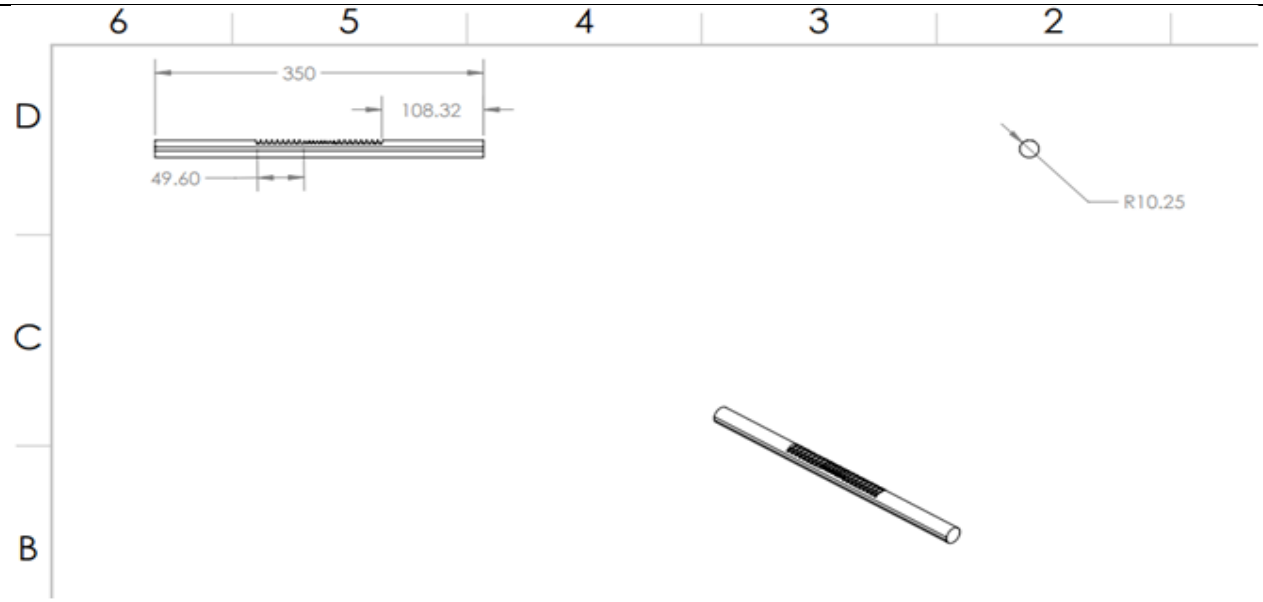


Figure 6 Isometric view and 2D view of rack gear

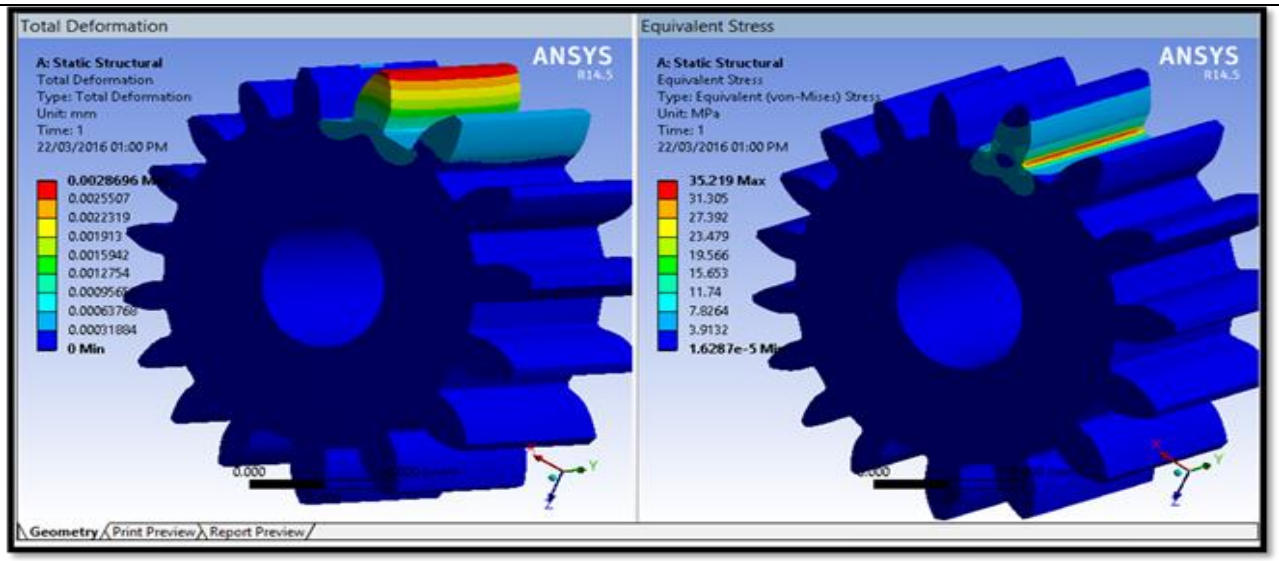


Figure 7 Analysis of pinion gear (i) Total deformation & (ii) Equivalent Stress, for module M = 2.0

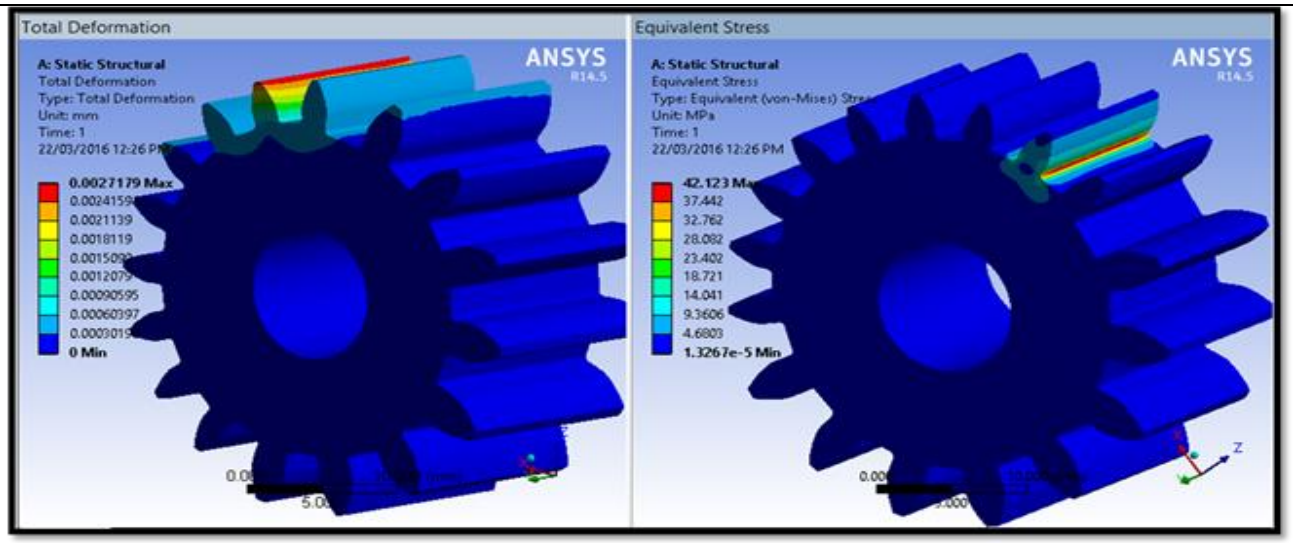


Figure 8 Analysis of pinion gear (i) Total deformation & (ii) Equivalent stress, for module M = 1.5

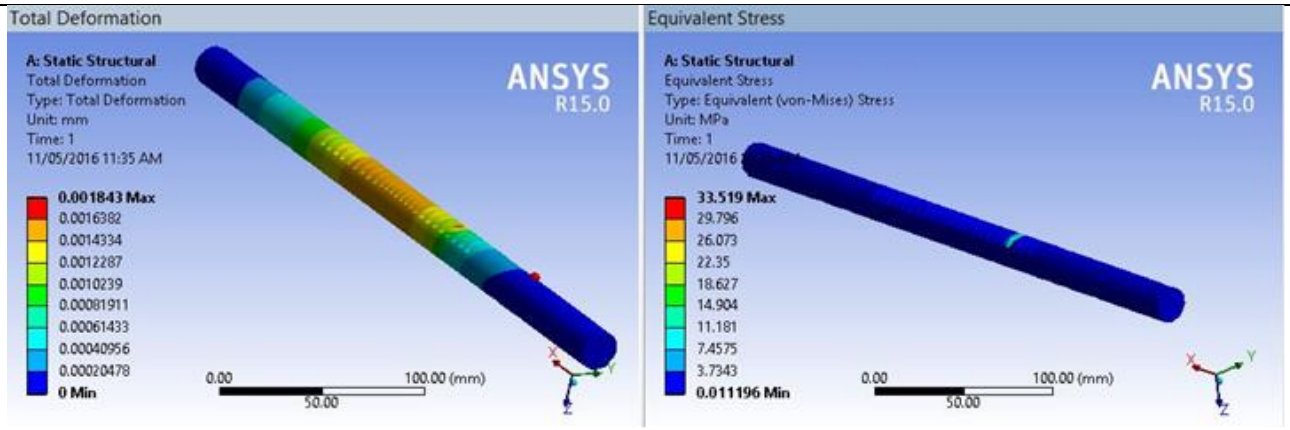


Figure 9 Analysis of rack gear (i) Total deformation & (ii) Equivalent Stress, for module M = 2.0

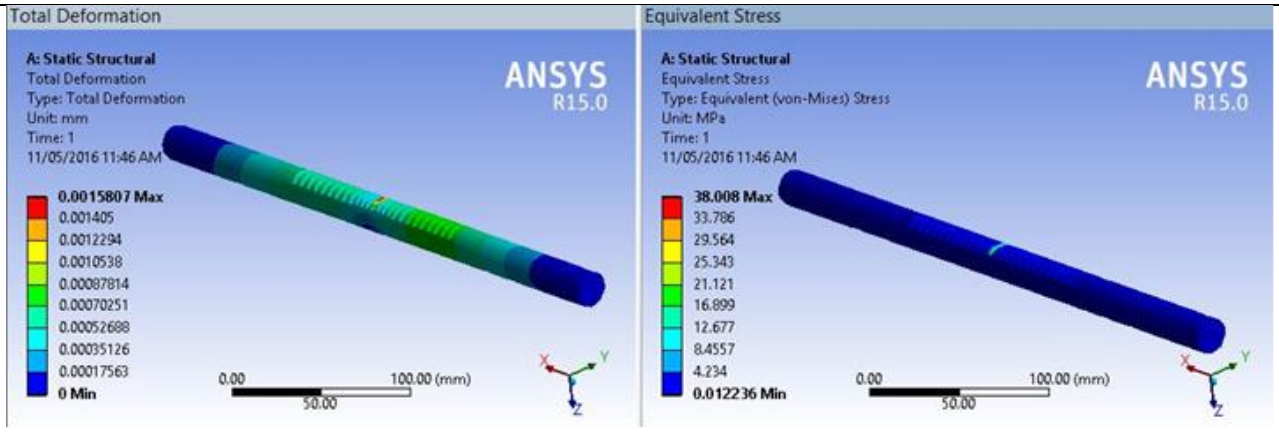


Figure 10 Analysis of rack gear (i) Total deformation & (ii) Equivalent Stress, for module M = 1.5

When we have started to design above variable rack and pinion, then at we faced to many problems related to design like (i) how to generate involute profile of a teeth (ii) how to arrange teethes of different module on a single pitch circle (iii) spacing between the teeth of module 1.5 & 2.0 (iv) Meshing errors, etc. While we are facing above mentioned problems, we have done lots of communication with our faculty advisor and also with a teammates, we also refers

## 5. Results

**Material : SS410 (For both rack and pinion)**

| | Pinion | Rack |
|---|---|---|
| **Fixed point** | Peripheral surface of centre hole | Both ends |
| **Total Deformation** | 0.0028696 mm | 0.00083926 mm |
| **Maximum Stress** | 42.123 MPa | 8.5339 MPa |
| **FOS** | 2.6038 | 2.3799 |

| | MATERIAL | PROPERTIES | |
|---|---|---|---|
| **RACK** | SS410 | Density | = 7700 Kg/m$^3$ |
| **PINION** | SS410 | Tensile Yield strength | = 310 MPa |
| | | Ultimate tensile strength | = 517 MPa |
| | | Young's modulus | = 180 GPa |
| | | Poisson's ratio | = 0.26 |
| | | Melting point temprature | = 1460℃ |
| | | Co-eff. of thermal expansion | =9.9 x 10$^{-6}$/℃ |

## 6. Claims

A VARIABLE RATIO RACK AND PINION COMPRISING:

1. Reduction in an applied force takes place as we move on towards the rack end or move on from the lower module to the higher module on the rack.
2. A circular driving pinion having addendum circle concentric with the driving axis of the steering column.
3. There is a change in radius of the pinion to maintain the continuous pitch circle diameter.
4. Module of the meshing gear changes with the rotation of it on either side of the pinion.
5. Module on the rack gear also changes as linear movement takes place while transmitting of power.
6. There is a suddenly large change in gear ratio, where the angular rotation of the pinion is small & when

the angular rotation of the pinion is large(>180º) then gear ratio changes gradually.(As we have limited angular rotation of pinion on 180º,we have provided only 2 no. of modules as 1.5 & 2.0)

## Conclusion

The objective of designing a variable rack and pinion steering system was performed successfully and various Ackermann's Geometry adjustments were also verified with the mostly possible steering sensitivity and minimized turning radius. And the different dynamic changes were incorporated and camber gain and stability was improved. However, as compare to single moduled gear (Rack and pinion) if we are going to use variable moduled gear (Rack and pinion) we are getting noticeable reduction in a applied force on a steering wheel by the driver, which again gives some comfort and also stability at the time of cornering.

## Reference

[1] Merritt Henry Edward," Variable-ratio toothed gearing mechanism", 23 Aug 1966
[2] A Bishop, "Rack and pinion variable ratio steering gear", 21 Aug 1973
[3] Megumu Higuchi,"Rack and pinion steering gear",9 Oct 1984
[4] MACDUFF; STANLEY I, "Variable ratio rack and pinion power steering gear",30 Sept 1975
[5] Petre Alexandru, Dragos Macaveiu, Catlin Alexandru,"Design and simulation of a steering gearbox with variable transmission ratio",6 Jan 2012
[6] LAND CRUISER (100 series),"VGRS (Variable Gear Ratio Steering) system"
[7] LEXUS feature"Lexus Variable Gear Ratio Steering"
[8] Design of machine element by V.B.BHANDARI
[9] Design data book PSG
[10] DON SHERMAN,"A Comprehensive Comparison Test of Electric and Hydraulic Steering Assist",Jan 2012
[11] Piotr A. Dudzinski,"Design characteristics of steering systems for mobile wheeled earthmoving equipment",1989
[12] "How the steering system works", Available @ http://www.howacarworks.com/basics/how-the-steering-system-works
[13] "Steering System", Available @ http://encyclopedia2.thefreedictionary.com/steering+system
[14] PAWAN KUMAR,YOGITHA MALPOTH,"Steering Control Mechanism"