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# Study on Different Material of Rack and Pinion By Numerical and Theoretical for Steering Gear Mechanism Applications

V. RAGHAVENDRA RAO[1], PRASHANT KUMAR SHRIVASTAVA[2], SHASHWATA BORAH[3], ABHISHEK GANGULY[4]
*[1,2] Mechanical Engineering Department, Dr A.P.J Abdul Kalam University, Indore (M.P.)*
*[3,4]Mechanical Engineering Department, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu*
*Corresponding Author Email : rag.velagapudi@gmail.com*

***Abstract— A rack and pinion is a type of linear actuator that comprises a circular gear (the pinion) engaging a linear gear (the rack). Together, they convert rotational motion into linear motion. Rotating the pinion causes the rack to be driven in a line. Conversely, moving the rack linearly will cause the pinion to rotate. The objective of the study is comparing the different material of Rack and pinion for steering mechanism in automobiles. The material was considered as 1, rack and pinion are made of Structural steel 2, rack is of epoxy carbon and pinion is of Structural steel , 3, rack is of Structural steel and pinion is of Epoxy carbon, and 4, rack and pinion are made of epoxy carbon. The numerical analysis was performed by the ansys and theoretical calculation was done by lewis equation. The responses are Total deformation, Equivalent stress, Equivalent strain, and bending stress from Numerical and theoretical data's. It was observed that Maximum deformation is less in epoxy carbon. The maximum Stress, Strain and deformation is less in epoxy carbon, when static analysis is performed. For Checking the bending stress the rack and pinion made of carbon epoxy resin achieves minimum bending stress values than the rack and pinion made from either steel or combination of both epoxy carbon woven fabric and steel. So, it was inferred that the Epoxy Carbon is a better material which can replace for Structural Steel.***

***Index Terms*— steering gear, epoxy carbon, Equivalent stress, steering mechanism.**

## I. INTRODUCTION

A rack and pinion is a type of linear actuator that comprises a circular gear (the pinion) engaging a linear gear (the rack). Together, they convert rotational motion into linear motion. Rotating the pinion causes the rack to be driven in a line. Conversely, moving the rack linearly will cause the pinion to rotate. A rack and pinion drive can use both straight and helical gears. Though some suggest helical gears are quieter in operation, no hard evidence supports this theory. Helical racks, while being more affordable, have proven to increase side torque on the datums, increasing operating temperature leading to premature wear. Straight racks require a lower driving force and offer increased torque and speed per percentage of gear ratio which allows lower operating temperature and lessens viscal friction and energy use. The maximum force that can be transmitted in a rack and pinion mechanism is determined by the tooth pitch and the size of the pinion as well as the gear ratio. For example, in a rack railway, the rotation of a pinion mounted on a locomotive or a railroad car engages a rack placed between the rails and helps to move the train up a steep gradient. For every pair of conjugate in volute profile, there is a basic rack. This basic rack is the profile of the conjugate gear of infinite pitch radius (i.e. a toothed straight edge).A generating rack is a rack outline used to indicate tooth details and dimensions for the design of a generating tool, such as a hob or a gear shaper cutter. While most consumers are familiar with rack and pinion systems for steering cars and small trucks, rack and pinion combinations have several other applications. Not only are rack and pinion systems used to help trains climb steep gradients, but they also provide better brake control, especially in snowy and icy conditions. Rack and pinion combinations are often used as part of a simple linear actuator, where the rotation of a shaft powered by hand or by a motor is converted to linear motion. The rack carries the full load of the actuator directly and so the driving pinion is usually small, so that the gear ratio reduces the torque required. This force, thus torque, may still be substantial and so it is common for there to be a reduction gear immediately before this by either a gear or worm gear reduction. Rack gears have a higher ratio, thus require a greater driving torque, than screw actuators. Typically, a driver will use a hand-operated steering wheel in front of them to direct the movement of the vehicle's front wheels in any desired direction via a column that may feature universal joints to allow for some degree of directional deviation. Tillers and rear-wheel steering are two examples of alternative configurations that can be seen on a wide variety of vehicles.

## II. RACK - AND - PINION

There is a lot of feedback and a very direct steering "feel" with the rack - and - pinion design. Gears consisting of a rack and pinion transform rotary motion into linear motion. The rack is the flat bar that the circular pinion interacts with the help of teeth. When the pinion is rotated, the rack will swivel until it reaches its stopping point. The stresses exerting on the tooth as the load is applied are the primary focus of this paper. The load is applied by turning the steering wheel. A better gear choice can be made by comparing the stress experienced on the tooth characteristics of various gear types. Solid Works is used for modelling, and Ansys for analysis[1].To design and analyze the rack and pinion mechanism and to reduce the weight of the components to increase the efficiency of the rack and pinion mechanism. The project describes the design and material selection methodology of the rack and pinion mechanism. The design of rack and pinion mechanism in such a manner that it satisfies the maximum loading conditions. The rack and pinion mechanism designed in the solid works CAD software and analyzed in the ANSYS workbench[2].The rack - and - pinion system is the primary type of steering used in cars. Most vehicles' suspension systems cannot function properly without it, making it an essential part. The primary goal of this study is to develop a rack-and-pinion steering for an ATV while simultaneously optimising its topology to cut down on weight. SolidWorks is used for modelling and the contact stress equation is used during the design process. The deformation dispersion is mapped out using ANSYS, which is then used for structural analysis. The functioning frequencies of the system are compared with the natural frequencies obtained through vibrational analysis with ANSYS. Based on this evaluation, a topological optimization is performed to produce a robust yet lightweight architecture[3]. Gear tooth root crack growth can be predicted using the presented computational model. Both the normal vibrating force acting at the apex of the single tooth contact and the lateral movement of the load along the tooth flank are considered as loading conditions. The root of a gear tooth is assumed to be where the crack begins in numerical analyses because this is where the stresses are highest. The development of a fatigue crack is then simulated using the elementary Paris equation. In order to calculate the necessary number of loading cycles N for a crack growth from the initial to the critical length, a displacement correlation method within the framework of the finite element method is used to obtain the functional relationship between the stress intensity factor and crack length. After determining the necessary material parameters with suitable test specimens, the model is then used to predict the development of fatigue cracks in a real gear fabricated from case carburized and ground steel 14CiNiMo13-4. The numerical analysis shows that under either loading condition, the predicted crack propagation live and crack path in a gear tooth root are very different[4].The wheels must be steered to move in the desired direction. Common mechanisms for accomplishing this include linkages, rods, and pivots. The caster angle is a fundamental principle. In order to turn a wheel, the pivot point must be located before the wheel itself. In this way, the steering can automatically center itself in direction of the motion. When the driver turns the wheel, motion is transmitted through a shaft hooked up to the steering column. Gears connect to the tie rods that drive the front wheels. The front wheels can be steered in any direction by adjusting the angle of the tie rods. The mechanism should allow the driver to easily adjust the vehicle's course, make tight turns, and then speed back out of them without any jerkiness. The steering mechanism must be designed to transmit as few road shocks as possible to the ground when the driver lets go of the steering lever. The steering mechanism directs the car where to go, allows for easy maneuvering, quick reorienting after turns, and minimal shock transmission[5]. The primary goal of RPG design is to achieve the desired steering ratio, eliminate RPG play, and maximize steering sensitivity. Rack and pinion design have been created in CATIA. The RPG's enclosure and clevis joint have undergone CAE to guarantee their reliability and safety. In this comparison, we look at how the newly developed RPG stacks up against the OEM gearbox in terms of price, weight, and the parameter of the steering gear ratio. The design results show that the new achieves the target steering ratio for 20% less weight and 40% less money than the OEM RPG [6]. Design and manufacturing FSAE vehicle steering system operation[7]. Discussed about the condition monitoring of gear pair using different vibration analysis[8]. Analysis of composite drive shaft using finite element analysis by using ansys[9]. Explained about the All Terrain Vehicles designing, manufacturing methodologies of rack and pinion mechanism for automobile applications[10]. Discussed about the design and finite element analysis of Rack and Pinion Mechanism by using Structural Steel and PLA materials[11]. There is no relevant studies done on different material combination of rack and pinion for steering gear mechanism. So this deals with the different material selection of 1, rack and pinion are made of Structural steel 2, rack and pinion are made of epoxy carbon, 3, rack is of Structural steel and pinion is of Epoxy carbon, and 4, rack is of epoxy carbon and pinion is of Structural steel by numerical and theoretical datas. This system aids in high-speed lane shifting and cornering. It deals with problems associated with sharp turning. It reduces the car's turning circle radius and enhances speed and agility and control while driving at high speeds, tends to result in neutral steering. Moreover, the components used in this system are simple to manufacture, and the components used are feasible, reliable, and readily available on the market. The system assembly is simple to install and light in weight, and it can be efficiently implemented in all sections of cars. As per kinetic analysis, our four-wheel steering system can reduce turning circle radius by 35% and minimizes turning circle radius by 58% per the system design. With the results of the analysis, all parts are safe within the safety limit [12-15].

## III. MATERIALS AND METHODS

*A. Material Selection*

A rack - and - pinion model has been designed using Solidworks, a solid modelling CAD/CAE program. Ansys is a suite of software that can simulate almost any aspect of engineering design, as it covers the full spectrum of physics. Steel is an iron alloy that, in comparison to pure iron, boasts increased mechanical properties resistance to the addition of a small amount of carbon. Carbon fiber is a material made up of very fine crystalline fibers of carbon that are extremely strong and are used to reinforce other materials, most commonly resins and ceramics. Epoxy-It refers to the raw materials for, or the cured forms of epoxy resins. Resins made up of epoxide groups are known as epoxy resins or polyepoxides.

*B. Methods*

Modeled by using design software Solid works tool folder and imported rack and pinion as shown in the figure 1.

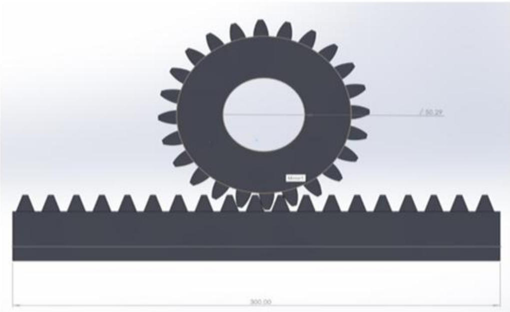


Figure1: Width of Rack and Pinion

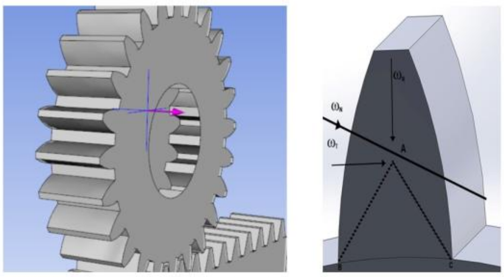
Rack length =300mm
No. of teeth = 24 ,
Pressure angle = 20 ,
gear width = 30mm ,
gear diameter = 100 mm ,
pitch diameter = 125mm ,
base diameter = 117.46 mm

Using Lewis Equation to find which rack and pinion mechanism is feasible on the basis of their load carrying capability.

1. Power to be transmitted
2. Speed of the driving gear
3. Speed of the driven gear
4. Centre distance

Beam strength of gear teeth ;-
(Lewis Equation)(acts like a cantilever beam)

The load carrying capability of tooth carrying gear. Due to normal load, vertical and horizontal forces are developed. Consider each tooth as a cantilever beam loaded by a normal force. As discussed earlier it is resolved into 2 components when normal force acts upon it, acting perpendicular and parallel to centerline BC.



(a) Orientation selection of the stackup shown in model (b) Gear tooth

Figure 2 Orientation of stack up for Gear model

For the gears to rotate the tangential force Wt should be the dominant force. The radian force Wr gets resists on gear bearing. Wt induces bending stress on the beam tends to break the tooth. Wr is positive radial component, induces a compressive stress at relatively smaller magnitude therefore is neglected.

Lewis considered gear teeth as a cantilever beams with a static normal force, F, applied at the tip. The following assumptions are made in the derivation: The full load is applied to the tip of a single tooth at the static condition. The radial component is negligible. The load is distributed uniformly across the full face width. Forces due to tooth sliding friction are negligible. The stress concentration in the tooth fillet is negligible.

Maximum value of bending stress at section BC,

$\sigma_b = (W_t)/(b * m * Y)$, $W_t = (P/v)*K_v$
b = face width=30mm , m = module = 5, Y = form factor = 0.124 - 0.684 (standard)
For the power 45kW, module = 5, velocity = 0.20, velocity factor = 202.5
For
Set1: Both rack and pinion are made of steel
$\sigma_b$ = 2.8*10^5 N/mm$^2$
Set2: Rack is of Epoxy carbon and pinion is of steel
$\sigma_b$ = 5.95*10^5 N/mm$^2$

Set3:Rack is of steel and pinion is of Epoxy carbon
$\sigma_b$ = 5.9*10^5 N/mm$^2$
Set4: Both rack and pinion are made of epoxy carbon woven
$\sigma_b$ = 1.6*10^5 N/mm$^2$

## IV. FINITE ELEMENT ANALYSIS

*A. Total deformation in Modal analysis*

In modal analysis of rack and pinion, the total deformation for structural steel is 2.7483, for the Epoxy carbon (rack) and Structural Steel (pinion) is 2.8633, for the Structural Steel (rack) and Epoxy carbon (pinion) is 2.8641 and for Epoxy carbon is 2.548. The minimum total deformation value was observed in both rack and pinion made with Epoxy carbon as shown in the figure 3.

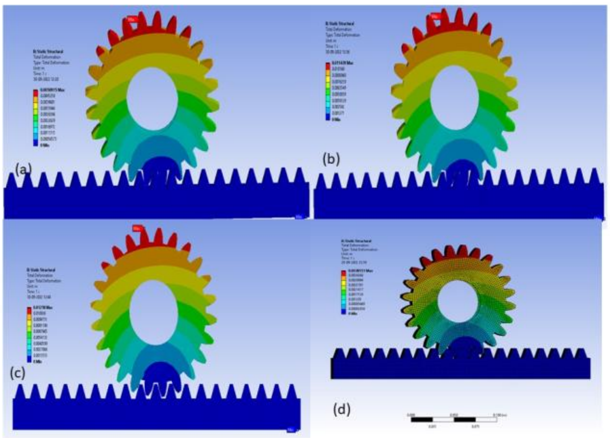



Figure3 : Modal Analysis - (a) Total Deformation for rack and pinion (structural steel)
(b) Total Deformation for rack (epoxy carbon woven) and pinion (structural steel)

(c) Total Deformation for rack (structural steel) and pinion (epoxy carbon woven)
(d) Total Deformation for rack and pinion (epoxy carbon woven)

*B. Total deformation in Static analysis*

In static analysis of rack and pinion, the total deformation for structural steel is 5.0915, for the Epoxy carbon (rack) and Structural Steel (pinion) is 11.439, for the Structural Steel (rack) and Epoxy carbon (pinion) is 12.18 and for Epoxy carbon is 3.8551. The minimum total deformation value observed in both rack and pinion made with Epoxy carbon.

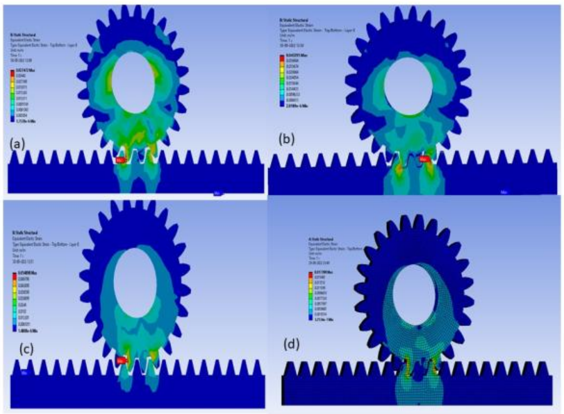



Figure 4 : Static Analysis - (a) Total Deformation for rack and pinion (structural steel)
(b) Total Deformation for rack (epoxy carbon woven) and pinion (structural steel)
(c) Total Deformation for rack (structural steel) and pinion (epoxy carbon woven)
(d) Total Deformation for rack and pinion (epoxy carbon woven)

*C. Equivalent stress in Static analysis*

In static analysis of rack and pinion, the equivalent stress for structural steel is 3.2822*10^9, for the Epoxy carbon (rack) and Structural Steel (pinion) is 7.9767*10^9, for the Structural Steel (rack) and Epoxy carbon (pinion) is 10.506*10^9and for Epoxy carbon is 1.6357*10^9. The minimum equivalent stress value observed in both rack and pinion made with Epoxy carbon.

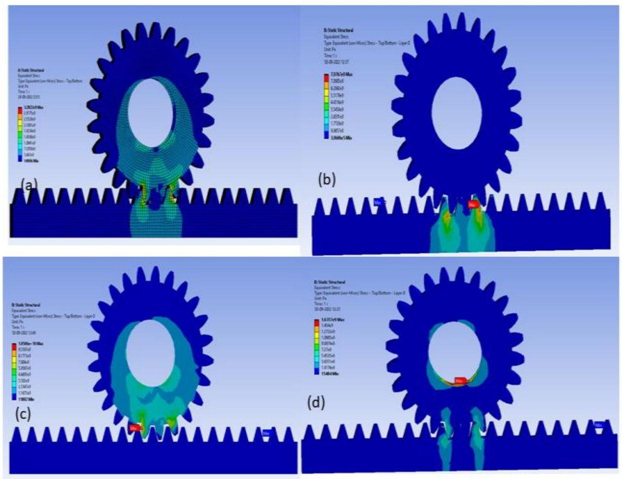



Figure 5: Static Analysis - (a) Equivalent stress for rack and pinion (structural steel)
(b) Equivalent stress for rack (epoxy carbon woven) and pinion (structural steel)
(c) Equivalent stress for rack (structural steel) and pinion (epoxy carbon woven)
(d) Equivalent stress for rack and pinion (epoxy carbon woven)

*D. Equivalent strain in Static analysis*

In static analysis of rack and pinion, the equivalent strain for structural steel is 0.027472, for the Epoxy carbon (rack) and Structural Steel (pinion) is 0.043295, for the Structural Steel (rack) and Epoxy carbon (pinion) is 0.054898 and for Epoxy carbon is 0.017398. The minimum equivalent strain value observed in both rack and pinion made with Epoxy carbon.

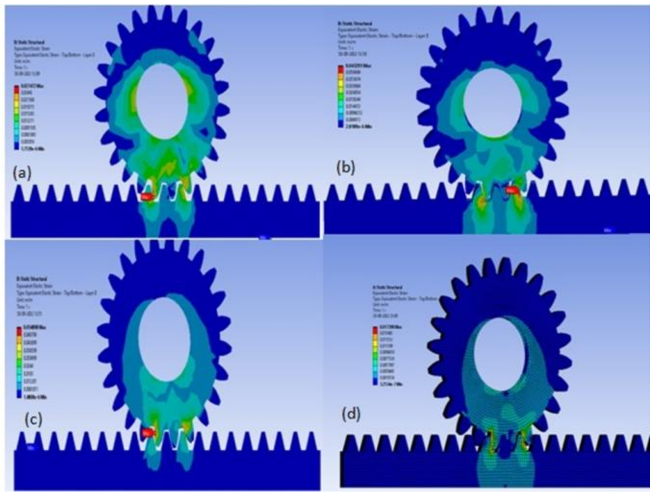



Figure 6: Static Analysis - (a) Equivalent strain for rack and pinion (structural steel)
(b) Equivalent strain for rack (epoxy carbon woven) and pinion (structural steel)
(c) Equivalent strain for rack (structural steel) and pinion (epoxy carbon woven)
(d) Equivalent strain for rack and pinion (epoxy carbon woven)

## V. RESULTS AND DISCUSSION

To calculate the equivalent stress for the rack and pinion systems, static analysis methods can be used. The equivalent stress is a representation of the maximum stress experienced by a component during operation and is typically used to assess the component's fatigue life.

When performing equivalent stress calculations for different materials, it is important to consider the material properties such as strength, elasticity, and ductility. Structural steel is a commonly used material in rack and pinion systems due to its high strength and durability. Epoxy carbon woven materials are also used in some applications due to their lightweight and high stiffness.

Table 1: Maximum Total deformation values in modal analysis

| SET.No. | Material | Total deformation (mm) |
|---|---|---|
| 1 | Structural Steel (rack and pinion) | 2.7483 |
| 2 | Epoxy carbon (rack) Structural Steel (pinion) | 2.8633 |
| 3 | Structural Steel (rack) Epoxy carbon (pinion) | 2.8641 |
| 4 | Epoxy carbon (rack and pinion) | 2.548 |

Table 2: Maximum values of Total deformation, Equivalent stress and Equivalent strain in static analysis

| SET. No. | Material | Total deformation (mm) | Equivalent Stress ($P_a$) | Equivalent Strain |
|---|---|---|---|---|
| 1 | Structural Steel (rack and pinion) | 5.0915 | 3.2822 *10^9 | 0.027472 |
| 2 | Epoxy carbon (rack) Structural Steel (pinion) | 11.439 | 7.9767 *10^9 | 0.043295 |
| 3 | Structural Steel (rack) Epoxy carbon (pinion) | 12.18 | 10.506 *10^9 | 0.054898 |
| 4 | Epoxy carbon (rack and pinion) | 3.8551 | 1.6357 *10^9 | 0.017398 |

From Table 1 , the maximum total deformation is less in epoxy carbon compared to that of Structural Steel and combination of both the materials, when modal analysis is performed.

From table 2, the Equivalent Stress, Strain and total deformation is less in epoxy carbon compared to that of Structural Steel and combination of both the materials, when static analysis is performed.

Lewis's equation is a method used in engineering to calculate the minimum required cross-sectional area of a member under a given loading condition. The equation takes into account the maximum bending stress and the maximum shear stress in the member.

Based on the data obtained theoretically and analytically, if it is observed that the epoxy carbon material achieves minimum bending stress values compared to structural steel or a combination of both materials for a rack and pinion system, then it is justifiable to conclude that epoxy carbon can be a substitute for structural steel in such applications.

## VI. CONCLUSION

This conclusion is based on the assumption that the other properties of the materials, such as stiffness, durability, and cost, are comparable or acceptable for the specific application. It is also important to consider any potential drawbacks of using epoxy carbon, such as its sensitivity to impact damage and its potential for delamination or cracking under certain loading conditions.

Overall, the decision to use epoxy carbon as a substitute for structural steel in a rack and pinion system should be based on a thorough analysis of the specific application and a comparison of the material properties and potential benefits and drawbacks. Lewis's equation can be a useful tool in this analysis, but it should be used in conjunction with other analytical and experimental methods to ensure a safe and optimal design.

## VII. FUTURE SCOPE

Having confirmed the optimal values using Ansys data and the Lewis equation, we can now produce the rack and pinion set. The set, rack and pinion made of epoxy carbon woven will be manufactured.

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