FABRICATION & DESIGN OF RACK AND PINION FOR FOUR WHEEL POWER STEERING

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Abstract
In standards 2 Wheels Steering Systems, the rear set of wheels are always directed forward and do not play an active role in controlled the steering. While in 4 Wheel Steering Systems, the rear wheels do play an active role for steering system, which can be guide at high as well as low speed. Production cars are designed to under steer and rare do they over steer. If a car could automatically compensate for an under steer/over steer problems, the driver would enjoy near neutral steering under varying operating condition. Also in situations like low speed cornering, vehicles parking and driving in city conditions with heavy traffic in tight spaces, driving would be very difficulty due to a sedan's larger wheel base and tracks width. So there is a requirement of mechanism which results in less turning radius

Keywords-Steering shaft, wheel, knucle, axle, rod,gear box, rack –pinion,universal shaft.

Introduction:
The evolution of automotive technology has seen continuous advancements, and power steering systems play a crucial role in enhancing vehicle maneuverability and driver comfort. Among various power steering mechanisms, the rack and pinion system stands out as a widely adopted and efficient solution. This mechanism converts rotational motion into linear motion, providing a responsive and precise steering experience.

Significance of Power Steering:

Power steering is an integral component in modern automobiles, ensuring ease of steering effort, especially at low speeds or during parking maneuvers. The rack and pinion system has gained prominence for its simplicity, reliability, and effectiveness in translating driver input into smooth and controlled vehicle movement.

Objective of the Project:

The primary goal of this project is to design and fabricate a rack and pinion system for four-wheel power steering, focusing on optimizing performance, reliability, and manufacturability. This involves intricate engineering considerations, material selection, and precision in the design process to ensure the system meets safety standards and enhances overall vehicle handling.

System Description
Steer System-
Many vehicles incorporate a power steering system the purpose of which is to reduce the driver effort to turn the steering wheel .The system usually is hydraulically operated with hydraulic pressure provided by a pump driven by a belt from the crank shaft. Driver system that is an older .V-belt type .These system used multiple V belt to drive the various accessories on the front of the engine .Most new vehicles use a single ribbed belt to drive all of the accessories. The power steering pump contains an integral fluid reservoir as well as the control and pressure regulating valves. The pump receives fluid from the reservoir and because it is belt driven by the crank, the pump operates whenever the engine is running. Steering linkage is a connection of various link between the steering gear box and

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the front wheel .The steering linkage transfer the side to side or front to rear movement of the pitman arm into left to right movement at the wheel.

Figure1. Mechanical Steer Systems

Rack-and-pinion Steering.

The rack and pinion steering system is simpler, lighter and generally cheaper than worm type system the steering column rotates a pinion gear that is meshed to a rack .The rack coverts the rotary motion directly to side to side motion and is connected to the tie rods. The tie rods cause the wheels to pivot about the kingpins thus turning the front wheels.

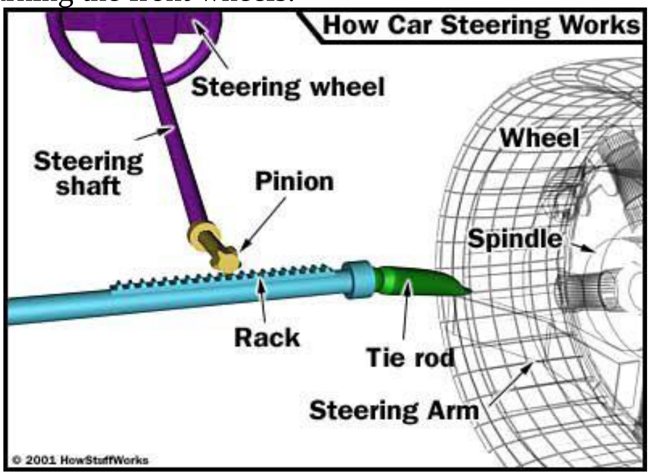

Figure 2- Mechanical Steer Rack inside View

Ackermann steering

The front wheels are placed over the front axles which are pivoted at the points .these points are fixed to the chassis .the back or rear wheels are placed over the back axle at the two ends of the differential tube. When the vehicles takes a turn the front wheels along with the respective axles turn about the respective pivoted points The rear wheels remain straight and do not turn. The steering is done by means of front wheels only.

In order to avoid skidding the two front wheels must turn about the same instantaneous centre I which lies on the axis of the rear wheels .If the instantaneous centre of the two front wheels do not coincide with the instantaneous centre of the rear wheels the skidding on the front or rear wheels will definitely take place which will cause more wear and tear of the tyres.

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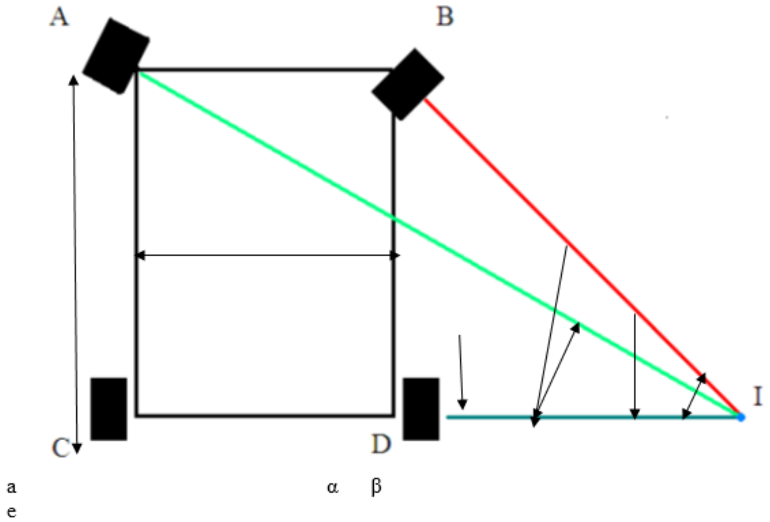

Figure3. Turn radius of the wheels

Let, a-wheel track
B-wheel base
Formula.-cotβ-cosα=c/h

Technical fundamentals.

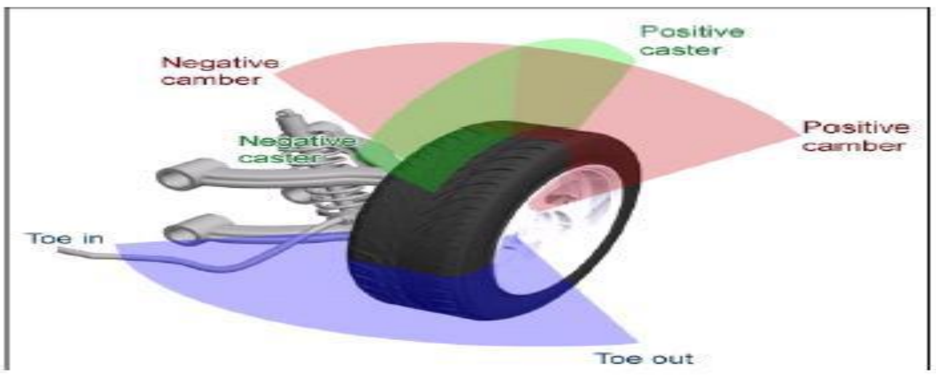

Figure5 - Wheels angles

2.5 Toe angle

This is an angle, or additive measuring, formed by a line drawn through the horizontal centers of each wheels relative to the center line of the vehicle. Toe can be read as individual, or the total of two wheels on the same axle. Proper toe will reduce scuff and improve tire life by reducing running toe to near zero.

If the pivot and the vertical axis of the wheels will be parallels, the effort to execute it would calculate with the next equation:

$$C = Fr*d$$

Where:

C: resistant torque
Fr: resistance to go round
d: distance of the torque

So we try to reduce this resistant torque decreasing the distance ``d´´.
Normally the distance ``d´´ although is short, exist and furthermore is necessary that exist a resistant torque in order to give a good stability to the steering because the wheel tends to become disorientated with the irregularly of the road the resist torque made that the wheels turn to in a good position.

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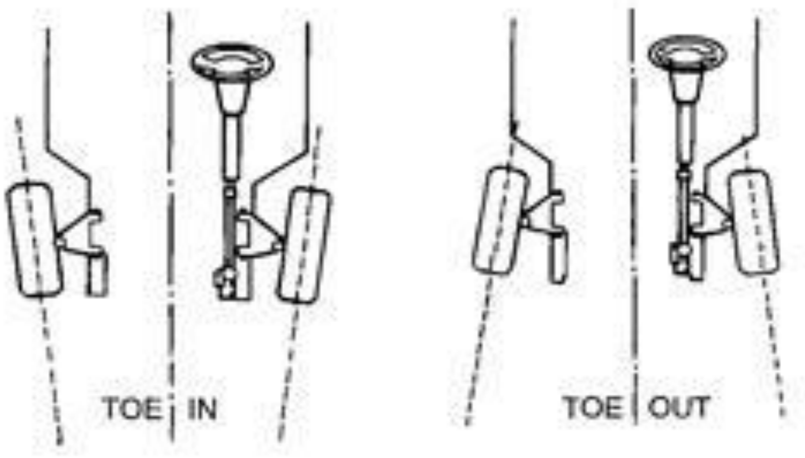

Figure6. Toe rod

Camber angle

Camber is the tilting of the top of the wheels inward or outward, toward or away from the automobile. Camber angles usually are very small of the order of 1 the camber angles .Positive camber is defined as the top of the wheel being tilted away from vehicle, where negative camber tilts the top of the wheel towards the vehicle

The upright supports flexure efforts equivalent to the momentum M = W*L.
Where: W: weight
L: distance

The fact to changed the camber has influence on the toe angle because if the camber angle increases the toe angle decreases and vice versa.

The camber angle equal to the caster angle provides the steering to keep the straight line by the cone effect.

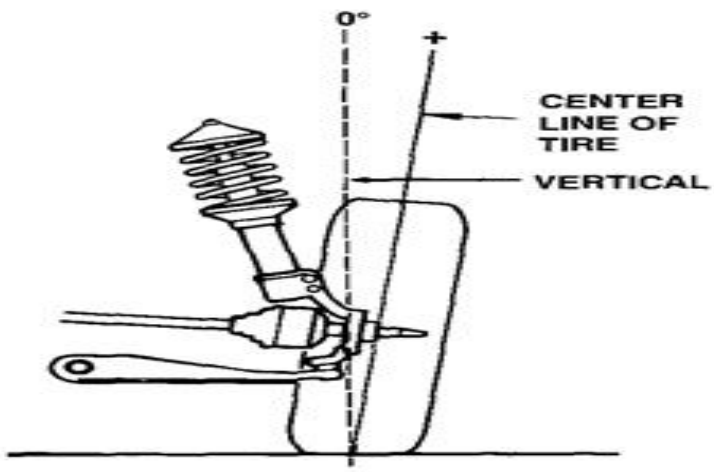

Figure 7- Camber angle

2.7 .Caster angle

Caster is a line drawn through the steering axis, compared to vertical. If the axis is tilted back at the top, the angle is positive, tilted forward is negative. Caster improves stability, steering wheel return and cornering.

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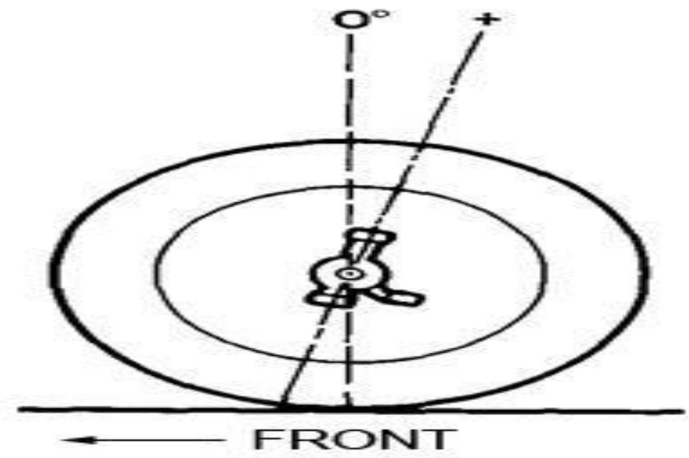

Figure8-Caster angle

The caster angle can also obtain situating the pivot in front of the vertical of the wheel axis. On both process the wheel is dragged and then it produces stability on the front wheels. We will bear in mind in this system the effects of the direction radius and the toe angle.

Literature Review

Before the appearance of the car the use of the rack and pinion was limited only to small vehicles because the steering proved too heavy and the improvements were not sufficiently suitable so it was necessary to make a lot of turns with the steering wheel in order to guide the wheels on the desirable trajectory. Nowadays this problem has been solved with the power-assisted steering.

Actually the rack and pinion steering system is simpler ,lighter and generally cheaper and the assembly is simply allowing the incorporation system that help on the driving as the power-assisted steering.

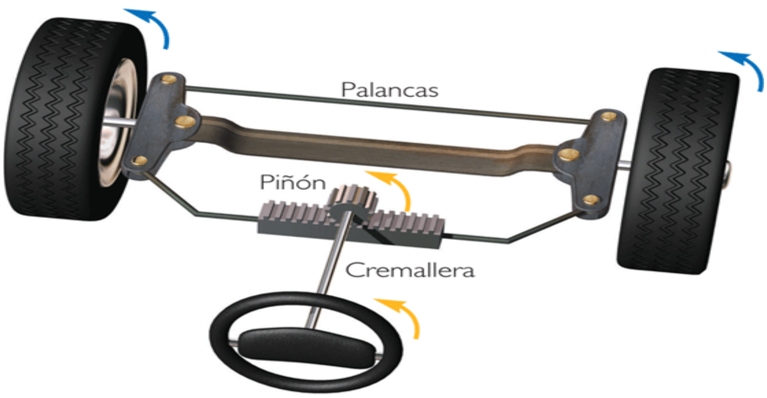

Figure 9 -Rack and pinion

. The system is connected directly with the tie rod and this one with the wheels having a high mechanical output. It is a great accuracy system, particularly in car with motors on the front part and with front-wheel-drive since decrease enormously the effort to do, is easly smooth, and has a good recuperation and is safety.

The steering system column ends with a pinion (generally helicoids) that engaged Constantly with a bar that is a rack. The rack moves inside a framework that is used as a guide and as protection of the outside agents. The rack is direct joint with the tie rod with ball-socket-joints transmitting the movements to the wheels. There are steering systems that have a power-assisted steering. This mechanism has the task of decrease the necessary effort at the time to drive the car. On

Industrial Engineering Journal
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Volume : 53, Issue 1, No. 2, January : 2024

the common cars the most used is the hydraulic system although is also used the pneumatic system or with an electrical system in the steering column

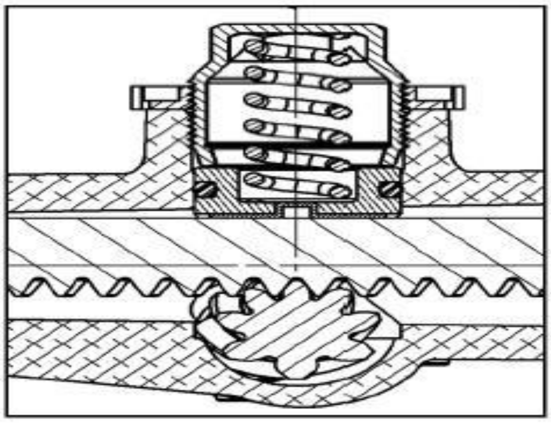

Figure10 -Rack and pinion front

Analysis

In orders to make the design of our rack and pinion for the steering box, we base our work on the choice of the rack and pinion which will produced a greater lateral displacement of the wheels with the same turn of the steering wheels.

We start saying that our steering column has a radius of 19 mm an adequate values for this kind of cars.

The others start point is that the rack and pinion must be the same modulus and the same materials. A suitable material for these elements is SAE 1045 steel which is simple to mechanism.

Carbon Steel SAE 1045

SAE 1045				
Chemical composition: C=0.45%, Mn=0.75%, P=0.04% max, S=0.05% max				
Property	**Value in metric unit**		**Value in US unit**	
Density	7.872 *10³	kg/m³	491.4	lb/ft³
Modulus of elasticity	201	GPa	29100	ksi
Thermal expansion (20 ºC)	11.7*10⁻⁶	ºC⁻¹	6.5*10⁻⁶	in/(in* ºF)
Specific heat capacity	486	J/(kg*K)	0.116	BTU/(lb*ºF)
Thermal conductivity	50.9	W/(m*K)	353	BTU*in/(hr*ft²*ºF)
Electric resistivity	1.62*10⁻⁷	Ohm*m	1.62*10⁻⁵	Ohm*cm
Tensile strength (hot rolled)	565	MPa	81900	psi
Yield strength (hot rolled)	310	MPa	45000	psi
Elongation (hot rolled)	16	%	16	%
Hardness (hot rolled)	84	RB	84	RB
Tensile strength (cold drawn)	625	MPa	90600	psi
Yield strength (cold drawn)	530	MPa	76900	psi
Elongation (cold drawn)	12	%	12	%
Hardness (cold drawn)	88	RB	88	RB

Industrial Engineering Journal
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In the followings pictures we can show the necessary parameters of the rack and pinion which we will operate to calculate the best possible design for our steering box.

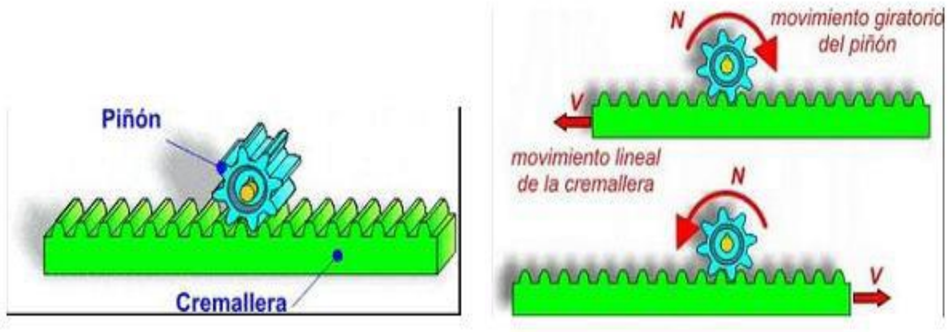

Figure11 -Rack and pinion parameters

N: velocity of the pinion turn

V: velocity of the rack

Z: number of pinion teeth

n: numbers of rack teeth in one cm

In order to calculate the velocity of the rack it is used the following equation:

$$v = N (z \div \eta) \text{ cm/sg}$$

And to calculate the distance that advance the rack in one complete turn of the pinion is:

$$d = (z \div \eta)$$

The positions of the steering box will be determinated with the dimensions of the wheels. For Formula S.A.E. we will be choose a wheel for the competitions with the Followings dimensions:

20.0 x 7.0 – 13 inches

If we translate to cm, we have an exterior diameter of 18 x 2.5 = 45cm. Bearing in mind that the steering box is joined with the wheel through the tie rods and the steering arms at the middle of the wheel. So we can obtain the distance of the steering box with the road and if we had the exacts measures of the cockpit we could calculate the distance of the steering box with the cockpit floor but the project of the chassis is studied in other project.

Finally the distance of the steering box to the road is:

$$45/ 2 = 22.5\text{cm}$$

Design and Calculation

For pinion,

Diametrical Pitch P = 12 teeth/inch

Number of teeths N= DP×(D-2÷DP)= 12×(2-2÷12)=22

Pitch diameter d = N/P = 22/12 = 1.833 inches

Modules m = d/N = 1.83/22 = .0833 inche

Circular pitch p = dπ/N = 3.14*.0833 = 0.263inche

Addendum = 1/P = 1/12 = 0.0833 inches

Dedendum = 1/P = 1/12 = 0.0833 inche

OD = 2*addendum + d

OD = 2*0.083 + 1.833 = 2 inches

For rack,
p' = 0.262 inches

p' = p*cosα

Here, α is pressure angle

p' = 6.3/22 inches

So (6.3/22)*cosα = 0.262

So, α = 24 degrees

ENGAGEMENT OF RACK AND PINION
Casing inner diameter = 25.4 mm

Rack diameter = 22 mm

Radial clearance = (25.4 – 22)/2 = 1.7 mm

Sleeve thickness = 1mm

STEERING KNUCKLE
Length of knuckle = 8.5"

The plate used is 4" wide and .6" thick.

Kingpin Angle or Steering Inclination Angles (SIA) = 13 degrees (To ensure smaller scrub radius and hence more responsive steering)

Caster angles = -8degrees (negative caster ensures more responses steering)

Upright design
We have designed, as we have said before, the upright separately of the steering arm in order to decrease the efforts on this element. By other hand we have designed the upright in order to be light. Finally the last parameter, we are going to design the upright inside a rim of 13 inches.

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Volume : 53, Issue 1, No. 2, January : 2024

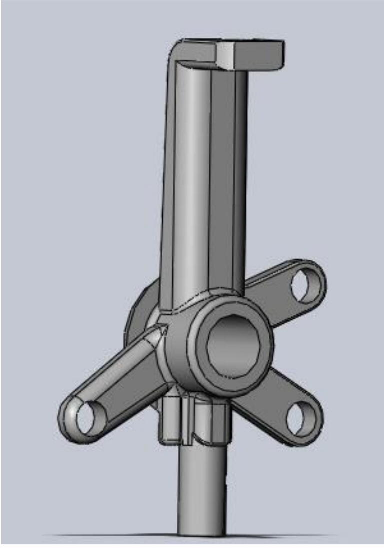

Figure12- Upright in solid works

.**Front upright**

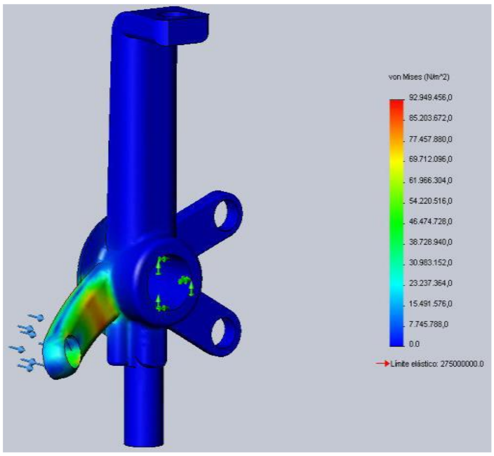

Figure13 - Stress analysis of the upright

Conclusion

Finally we have finished our design. We have to design the steering system for a
Formula S.A.E. car describes all the elements and choosing the good options to make it and to can adapted in a whole project to a cars with the characteristics of Formula S.A.E.

We started the project investigating about this kinds of vehicle and about the steering system in general in a cars. The first step was to know the formula S.A.E. rules and the theoretical fundamentals about the steering as Ackermann or the Jeanteaud Trapezium. These concepts have been in mind during the design of our elements.

The elements rack and pinions, tie rods, steering arms and the upright we have determinate the Jeantaud trapeziums and we have obtained the connections between the turn angles of the front wheels with the wheel base and the tracks. According to Jeantaud study we have design the elements in orders to the extensions of the lines that joint the end of the tie rods with the point where the steering arm is joined with the uprights finished on the center of the rear track in order to achieved a good performance of the vehicles.

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