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Design and fabrication of variable steering ratio mechanism for light Motor vehicle

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ABSTRACT

To facilitate easy and proper steering of the vehicle while negotiating a turn, as per the requirements of driver in different situations like hair pin bends in hilly regions, sudden turns in highways and city streets or in sports car during race events an improved steering system is needed to address these problems. The steering arrangement used in a normal automobile was investigated and to solve the above problems a variable steering ratio mechanism was designed and fabricated, with the aim to determine if incorporation of variable steering ratio mechanism will make an improvement in the steady and transient state handling of the automobile. The size of the pinion gear and the number of teeth on the gear determine the rack-and-pinion steering ratio. The steering wheel must be turned one revolution to turn the front wheels one sixteenth of a turn, the steering ratio is 1 to 1/16. Reversing the numbers gives a ratio of 16 to 1, or 16:1. This steering ratio is always fixed. A variable steering ratio mechanism was fabricated by using constant mesh type gears from Bajaj-Super and steering mechanism from Tata-Nano. Gear housing using wood is created and gear shifting arrangement incorporated. It was observed that on engaging the 1st gear steering ratio is increased to 9.92:1. On engaging the 2nd gear steering ratio is increased to 7.20:1, On engaging the 3rd gear steering ratio is increased to 4.96:1 On engaging the 4th gear steering ratio is increased to 3.52:1. The effort required for steering is increased due to these ratios as energy is lost due to friction. This mechanism can only be practical if used in conjugation with power assist.

Keywords: - Variable Steering Ratio Mechanism, Constant Mesh Gear Box, Steering Wheel, Power Assist

1. INTRODUCTION

1.1 Automobile

An automobile, auto car, motor car or car is a wheeled motor vehicle used for transporting passengers, which also carries its own engine or motor. Most definitions of the term specify that automobiles are designed to run primarily on roads, to have seating for one to eight people, to typically have four wheels, and to be constructed principally for the transport of people rather than goods. The term motorcar has also been used in the context of electrified rail systems to denote a car which functions as a small locomotive but also provides space for passengers and baggage. These locomotive cars were often used on suburban routes by both interurban and intercity railroad systems.

1.2 History of Automobile

The large-scale, production-line manufacturing of affordable automobiles was debuted by Ransom Olds at his Oldsmobile factory in 1902 based on the assembly line techniques pioneered by Marc Isambard Brunel at the Portsmouth Block Mills, England in 1802. The assembly line style of mass production and interchangeable parts had been pioneered in the U.S. by Thomas Blanchard in 1821, at the Springfield Armory in Springfield, Massachusetts. This concept was greatly expanded by Henry Ford, beginning in 1914. As a result, Ford's cars came off the line in fifteen minute intervals, much faster than previous methods, increasing productivity eightfold (requiring 12.5 man-hours before, 1 hour 33 minutes after), while using less manpower. It was so successful, paint became a bottleneck. Only Japan black would dry fast enough, forcing the company to drop the variety of colors available before 1914, until fast-drying Duco lacquer was developed in 1926. This is the source of Ford's apocryphal remark, "any color as long as it's black". In 1914, an assembly line worker could buy a Model T with four months' pay.

Ford's complex safety procedures—especially assigning each worker to a specific location instead of allowing them to roam about—dramatically reduced the rate of injury. The combination of high wages and high efficiency is called "Fordism," and was copied by most major industries. The efficiency gains from the assembly line also coincided with the economic rise of the United States. The assembly line forced workers to work at a certain pace with very repetitive motions which led to more output per worker while other countries were using less productive methods.

In the automotive industry, its success was dominating, and quickly spread worldwide seeing the founding of Ford France and Ford Britain in 1911, Ford Denmark 1923, Ford Germany 1925; in 1921, Citroen was the first native European manufacturer to adopt the production method. Soon, companies had to have assembly lines, or risk going broke; by 1930, 250 companies which did not, had disappeared.

Development of automotive technology was rapid, due in part to the hundreds of small manufacturers competing to gain the world's attention. Key developments included electric ignition and the electric self starter (both by Charles Kettering, for the Cadillac Motor Company in 1910–1911), independent suspension, and four-wheel brakes.

Since the 1920s, nearly all cars have been mass-produced to meet market needs, so marketing plans often have heavily influenced automobile design. It was Alfred P. Sloan who established the idea of different makes of cars produced by one company, so buyers could "move up" as their fortunes improved.

Reflecting the rapid pace of change, makes shared parts with one another so larger production volume resulted in lower costs for each price range. For example, in the 1930s, La Salles, sold by Cadillac, used cheaper mechanical parts made by Oldsmobile; in the 1950s, Chevrolet shared hood, doors, roof, and windows with Pontiac; by the 1990s, corporate power trains and shared platforms (with interchangeable brakes, suspension, and other parts) were common. Even so, only major makers could afford high costs, and even companies with decades of production, such as Apperson, Cole, Dorris, Haynes, or Premier, could not manage: of some two hundred American car makers in existence in 1920, only 43 survived in 1930, and with the Great Depression, by 1940, only 17 of those were left.In Europe much the same would happen.

1.3 Motivation for choosing the problem

In rough terrain, controlling the steering in a straight path is an arduous task as it requires a great deal of effort. It calls for greater stability and slower steering. During maneuverability, greater steering is required and quicker response is desire. Thus, the demand of steering is variable and the steering should be capable of adapting itself to the requirements of situations.

1.4 Rationale of study

Reason of this project is to provide versatile steering ratio to the driver and ease in controlling over rough terrain.

1.5 Problem Statement

Designing and fabrication of a steering system which can provide the driver a liberty to choose different steering ratio for different situations or terrains.

2. DEFINITION & CONCEPT

This concept has been evolved from the problem faced during driving the car on highway and then in the busy streets of city, where we found that there is the need of higher steering ratio at highways and lower steering ratio in those busy city streets. In racing events such as BAJA SAE, formula racing where a driver is required to turn at high speed so lower steering ratios are required. Then after reviewing all the literature regarding the steering ratio and different types of steering system available in the market, we thought to design the system which will give the steering ratio according to the need of the driver, whether he is on highway or city.

2.1 Steering Ratio

Mechanical advantage is the ratio of the output force to the input force applied to a mechanical device. With mechanical advantage, a small input force can produce a large output force. In the steering system, the driver applies a relatively small force to the steering wheel. Higher steering ratio reduces the effort required for steering. However, the steering wheel must be turned more than with a lower steering ratio. Steering ratio is determined by steering-linkage ratio and the gear ratio in the steering gear. Steering-linkage ratio for pitman-arm steering gears depends on the relative length of the pitman arm and the steering arm. When the two arm are the same length, the steering-linkage ratio is 1:1. If the pitman arm is twice as long as the steering arm, the ratio is 1:2. In the rack-and-pinion steering gear, steering ratio may be determined by the number of teeth on the pinion gear. The fewer the number of teeth, the higher the ratio.

2.2 Principle behind Variable steering ratio mechanism

Variable steering ratios can be achieved by using toothed gears to change the velocity ratio between steering wheel and steering shaft i.e. shaft joined to rack and pinion mechanism. This goal can be achieved by either using internal gears or external gears.

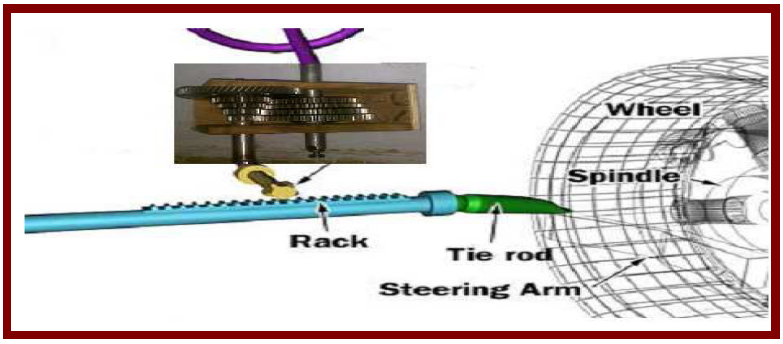

Figure-1 Variable steering ratio mechanism

The relative speed of two meshed gears is determined by the number of teeth in each gear. This Ratio. Linear velocity of gears remain same but due to different number of teeth rpm of driven and driver shaft changes.

$$\boxed{\frac{T_1}{T_2} = \frac{N_2}{N_1}}$$

T1= Number of teeth on driver gear
T2= Number of teeth on driven gear
N1= Speed of driver gear
N2= Speed of driven gear

3. CAR STEERING SYSTEM

3.1 Steering Mechanism

3.1.1 Function

Steering is the term applied to the collection of components, linkages, etc. which will allow a vessel (ship, boat) or vehicle (car, motorcycle, and bicycle) to follow the desired course. An exception is the case of rail transport by which rail tracks combined together with railroad switches provide the steering function. The most conventional steering arrangement is to turn the front wheels using a hand–operated steering wheel which is positioned in front of the driver, via the steering column, which may contain universal joints (which may also be part of the collapsible steering column design), to allow it to deviate somewhat from a straight line. Other arrangements are sometimes found on different types of vehicles, for example, a tiller or rear–wheel steering. Tracked vehicles such as bulldozers and tanks usually employ differential steering that is, the tracks are made to move at different speeds or even in opposite directions, using clutches and brakes, to bring about a change of course or direction.

3.1.2 Principle of Automobile Steering

For a car to turn smoothly, each wheel must follow a different circle. Since the inside wheel is following a circle with a smaller radius, it is actually making a tighter turn than the outside wheel. If you draw a line perpendicular to each wheel, the lines will intersect at the center point of the turn. The geometry of the steering linkage makes the inside wheel turn more than the outside wheel.

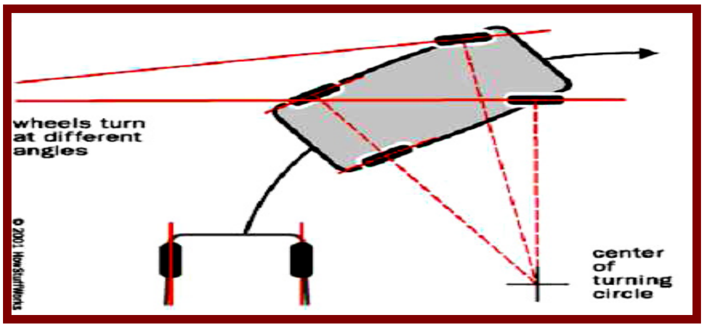

Figure-2 Turning of Car

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3.1.3 Mechanism

99% of the world's car steering systems are made up of the same three or four components. The steering wheel in connections with the steering system connects to the track rod, which connects to the tie rods, which connect to the steering arms. The steering system can be one of several designs, which we'll go into further down the page, but all the designs essentially move the track rod left-to-right across the car. The tie rods connect to the ends of the track rod with ball and socket joints, and then to the ends of the steering arms, also with ball and socket joints. The purpose of the tie rods is to allow suspension movement as well as an element of adjustability in the steering geometry. The tie rod lengths can normally be changed to achieve these different geometries.

3.2 Davis Steering Gear

The Davis Steering gear has sliding pair; it has more friction than the turning pair, therefore the Davis Steering Gear wear out earlier and become inaccurate after certain time. This type is mathematically Accurate. The Davis gear mechanism consists of cross link KL sliding parallel to another link AB and is connected to the stub axle of the two front wheel by levers ACK and DBK pivoted at A and B respectively. The cross link KL slides in the bearing and cross pins at its ends K and L. The slide blocks are pivoted on these pins and move with the turning of bell crank levers as the steering wheel is operated. When the vehicle is running straight the gear is said to be in its mid-position. The short arms AK and BL are inclined an angle 90 t α to their stub axles AC and BD respectively. The correct steering depends upon the suitable selection of cross arm angle α, and is given by

$$\tan \alpha = b/2l$$

Where b= AB = distance between the pivots of front axle.
l=wheel base

3.3 Ackermann Steering Gear

Ackermann steering geometry is a geometric arrangement of linkages in the designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radius. It was invented by the German Carriage Builder Georg Lankensperger in Munich in 1817, then patent by his agent in England Rudolph Ackermann (1764-1834) in 1818 for horse drawn carriage. The intention of Ackermann geometry is to avoid the need for tyres to slip sideways when following the path around a curve. The geometrical solution to this is for all wheels to have their axles arranged as radii of a circle with a common centre point. As the rear wheels are fixed, this centre point must be on a line extended from the rear axle. Intersecting the axes of the front wheels on this line as well requires that the inside front wheel is turned, when steering, through a greater angle than the outside wheel.

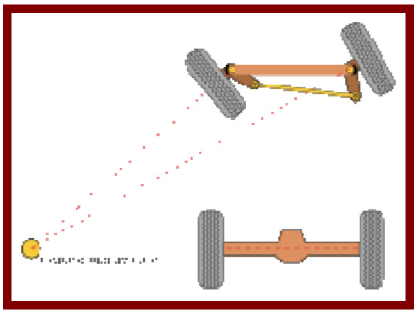


Figure-3 Ackerman Steering Geometry

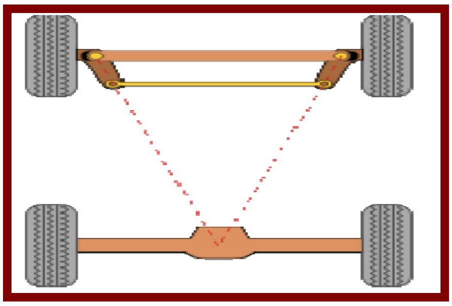


Figure-4 Simple Approximation for designing Ackermann geometry

Modern cars do not use pure Ackermann steering, partly because it ignores important dynamic and compliant effects, but the principle is sound for low speed manoeuvres.

3.4 Rack-and-pinion Steering

Rack-and-pinion steering is quickly becoming the most common type of steering on cars, small trucks and SUVs. It is actually a pretty simple mechanism. A rack-and-pinion gear set is enclosed in a metal tube, with each end of the rack protruding from the tube. A rod, called a tie rod, connects to each end of the rack. The pinion gear is attached to the steering shaft. When you turn the steering wheel, the gear spins, moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle.

The rack-and-pinion gear-set does two things:

· It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels.

· It provides a gear reduction, making it easier to turn the wheels.

3.5 Power Rack-and-pinion

When the rack-and-pinion is in a power-steering system, the rack has a slightly different design. Part of the rack contains a cylinder with a piston in the middle. The piston is connected to the rack. There are two fluid ports, one on either side of the piston. Supplying higher-pressure fluid to one side of the piston forces the piston to move, which in turn moves the rack, providing the power assist.

4. DESIGN& FABRICATION

Scooter’s constant mesh type gear-box is used. These are made of splined shaft and constantly meshing gears. Spur gears are used with pressure-angle of 20.5^o. Splines are used to engage a particular driving gear to driven gear. The splined-shaft is reciprocated to and fro, using a lever. For fabrication of variable steering mechanism we have chosen rack and pinion mechanism and fabricated it with a gear box to fabricate variable steering ratio mechanism.

4.1 Material Used

This section describes about the material used for the fabrication of variable steering ratio mechanism, their specification etc.

4.1.1 Tata Nano Steering Mechanism

The steering gear consists of the rack, pinion, and related housings and support bearings. Turning the steering wheel causes the pinion to rotate. Since the pinion teeth are in mesh with the rack teeth, turning the pinion causes the rack to move to one side. The rack is attached to the steering knuckles through linkage, so moving the rack causes the wheels to turn.

4.1.2 Gears Specification & Ratios

We have used constant mesh type gearbox of Bajaj Super for the fabrication of our project. All the main shaft gears are in constant mesh with the cluster gears. This is possible because the gears on the main shaft are not splined to the shaft, but are free to rotate on it. With a constant-mesh gearbox, the main drive gear, cluster gear and all the main shaft gears are always turning, even when the transmission is in neutral. Alongside each gear on the main shaft is a dog clutch, with a hub that's positively splined to the shaft and an outer ring that can slide over against each gear. Both the main shaft gear and the ring of the dog clutch have a row of teeth. Moving the shift linkage moves the dog clutch against the adjacent main shaft gear, causing the teeth to interlock and solidly lock the gear to the main shaft. To prevent gears from grinding or clashing during engagement, a constant-mesh, fully "synchronized"manual transmission is equipped with synchronizers. A synchronizer typically consists of an inner-splined hub, an outer sleeve, shifter plates, lock rings (or springs) and blocking rings. The hub is splined onto the main shaft between a pair of main drive gears. Held in place by the lock rings, the shifter plates position the sleeve over the hub while also holding the floating blocking rings in proper alignment. A synchronized inner hub and sleeve are made of steel, but the blocking ring, the part of the synchronizer that rubs on the gear to change its speed is usually made of a softer material, such as brass. The blocking ring has teeth that match the teeth on the dog clutch. Most synchronizer performs double duty the synchronizer in one direction and lock one gear to the main shaft. Push the synchronizer the other way and it disengages from the first gear, passes through a neutral position, and engages a gear on the other side.

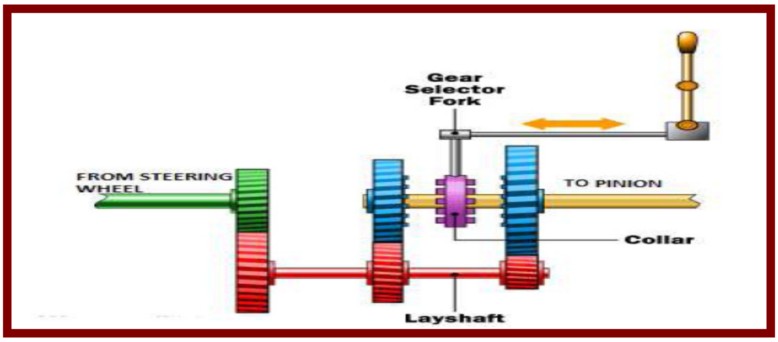


Figure-5 Constant Mesh Gear Arrangement

Table-1 Gear Specification

Lay Shaft No. of Teeth	Main Shaft No. of Gears	Gear Ratio
21	34	0.62
17	38	0.45
13	42	0.31
13	60	0.22

4.2 Fabrication

Bajaj super constant mesh type gears are assembled in a wooden housing. For smooth running of gears, they were aligned and turned to ensure proper clearance with the hole. We have used running fit assembly for our work. Wooden housing was chosen as it is light- weight, easy to fabricate and less expensive than metal housing. The steering column was cut into two parts. One part is attached to gear and the other one to the counter gear. Welding was performed using MMAW due to easier handling. To ensure concentricity of the shaft and the cut-rods, special fixtures were designed. The slag was chipped off and weld was cleaned.

Figure-6 Gear Box

Figure.7 Rack and pinion

Figure-8 Final assembly

4.3 Experimentation

- Number of teeth are counted on each gear
- Diameter is measured by first measuring the addendum diameter, which is the length between two teeth situated opposite to each other, along the periphery. Standard value of addendum is 1.157*m, where "m" is module.
- From the module calculated, diameter can be calculated using the relation, m=d/ T, where T is the no. of teeth on the gear.

Table-2 Diameter and No. of Teeths

Lay Shaft		**Main Shaft**		**Module**	**Gear Ratio**
Diameter (CM)	Teeth	Diameter (CM)	Teeth		
5.4	21	9	34	0.26	0.62
4.4	17	10	38	0.26	0.45
3.4	13	11	42	0.26	0.31
2.6	13	12	62	0.20	0.22

Figure-9 gears

5. RESULTS AND DISCUSSION

In this section company manufactured steering is compared with variable steering ratio mechanism. Company-manufactured steering usually has gear-ratio as 16:1, which is the ratio between rack and pinion. Introducing a gear-box between the two cut -pieces of steering rod changes the overall steering ratio, without changing the original gear-ratio between rack and pinion. By having different teeth on gear and counter-gear, different ratios can be realized. Gear-ratio of gear box can be calculated by counting the number of teeth of the meshing gears. Mathematically, gear-ratio=no. of teeth on driver gear/no. of teeth on driven gear.

5.1 Steering Ratios

Company built steering ratio is 16:1.
New steering ratio(s) =original*gear ratio(s)

Table-3 Final Ratio obtained

Lay Shaft	Main Shaft	Gear Ratio	Final Ratio
21	34	0.62	9.92:1
17	38	0.45	7.20:1
13	42	0.31	4.96:1
13	60	0.22	3.52:1

Table-3 reveals that by successive gears give different outputs we are able to modify the gear ratios from 16:1 to 9.92:1 on engaging 1st gear, 7.20:1 for 2nd gear, 4.96:1 for 3rd gear and 3.52:1 for 4th gear. As can be seen from the table, different ratios have been realized by using gears having different teeth. This gear ratio was later found to be equal to velocity ratio.

5.2 Comparison with existing steering design

We can steer quickly at high speeds as different ratios offer us the freedom to choose by how much we want to steer. This assembly is Light weight & Economic we were able to achieve our stated objectives at a cost of around Rs 5000 and when in mass production it will not cost more than Rs 1000. It can be easily installed in passenger cars. The assembly is Ergonomic i.e. shifting is easy you only need to pull the shifter Increased effort is under control in hilly regions by choosing higher ratios.

5.3 Justification of present work

The purpose of the Variable Steering Ratio (VSR) is to adapt the overall ratio between hand wheel angle and (averaged) road wheel to the current driving situation. The driving situation can, for instance, be determined by the vehicle's velocity and pinion angle. The point in varying the ratio dependent on velocity is to decrease it (compared to the mechanical ratio) when driving at very low velocities, which is of particular use for example during parking man oeuvres. Then the driver only has a small steering effort (in terms of turning the hand wheel) due to this direct steering ratio in order to manoeuvre the car smoothly into the parking space. At higher vehicle velocities the steering ratio becomes increasingly indirect up to the level of a conventional steering system (or even beyond).

5.4 Economic consideration

Table-4 Cost Analysis

Components	Cost
Gear	Rs. 500
Counter gear	Rs.500
Wooden Housing	Rs.200
Steering Column	Rs.1000
Steering Wheel	Rs. 5000
Fabrication Cost	Rs.500
Rack & pinion	Rs.5000
Total Cost	Rs. 12700

The cost of mechanism over that of existing steering system is Rs. 12700. This mechanism gives four extra options of steering ratios to the driver which can be very critical and useful. Also it is a retro fitting device which can be implemented without much change in design. Steering column has been displaced by 7 cm but incorporation of universal joint avoids any inconvenience to driver.

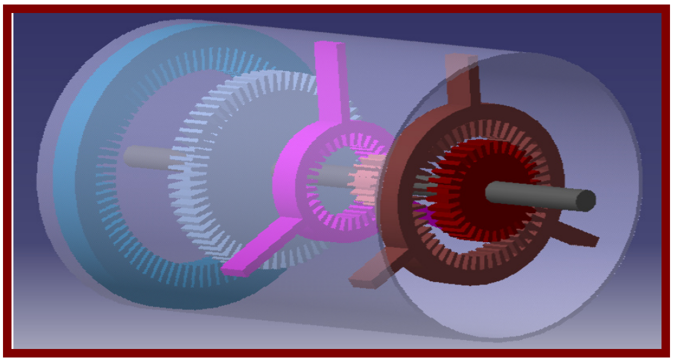
6. CONCLUSIONS

The following conclusions can be drawn from the present study:
1. On engaging the 1st gear steering ratio is increased to 9.92:1
2. On engaging the 2nd gear steering ratio is increased to 7.20:1
3. On engaging the 3rd gear steering ratio is increased to 4.96:1
4. On engaging the 4th gear steering ratio is increased to 3.52:1

5. The effort required for steering is reduced due to these ratios but energy is lost due to friction. This mechanism can only be practical if used in conjugation with power assist
6. Rack and pinion mechanism can also be reduced leading to significant reduction in manufacturing cost of rack and pinion which can offset the cost of variable steering ratio mechanism.

7. SCOPE FOR FURTHER IMPROVEMENT

The design of this mechanism evolves from the thought that why we can't use internal tooth gears for the same purpose as we are doing with external tooth gears. The basic design is like a cylinder packet in which the steering wheel is attached to the cylindrical housing which holds internal tooth gears and another shaft which holds external tooth gears ultimately which will move to the rack for transmission of steering rotation.



Figue-10 Full set of Alternative Design

Now, the shifting mechanism will be in a different manner than that of the proposed mechanism in a way that there is the shifting slider in the shaft which is going to the rack. The CAD model which represents the basic design of shifter mechanism is shown below.

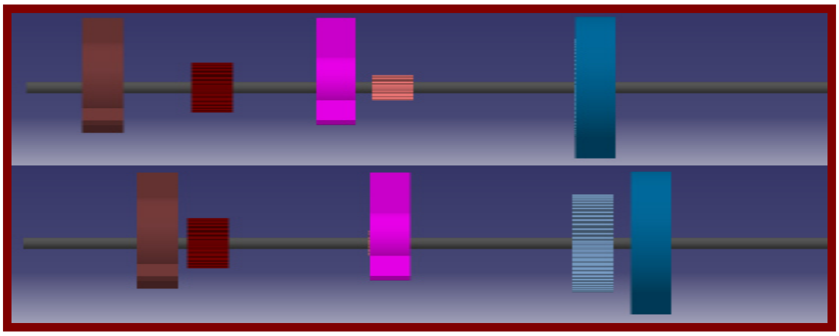


Figure-11 Shifting Mechanism

Effort decreasing mechanism i.e. power steering can be employed to reduce the effort required for steering at low ratios. Part of the rack contains a cylinder with a piston in the middle. The piston is connected to the rack. There are two fluid ports, one on either side of the piston. Supplying higher pressure fluid to one side of the piston forces the piston to move, which in turn moves the rack, providing the power assist.

REFERENCES

1. Crouse William H and Anglin Donald L,(2008) "Automotive Mechanics, Mcgraw Hill".
2. Daniel Nuviala Civera, (2011) "Description and design of the steering system for a Formula Student ca".
3. Ikegaya (Hamana-Gun, Japan), Tadao Itou (Toyohashi-shi, Japan, Steering Device with Variable Steering Ratio Mechanism**,** Isao Japanese Laid-open Patent Application (Tokkai) 2000-211541.
4. Khurmi R.S.& Gupta J.K., (2008) Theory Of Machines, S.chand, Delhi, 2008
5. Sebastien Feve & Alexandre Huret**,** (2007) Vehicle steering study, Georgia institute of technology.
6. Tom Murphy and Brian Corbett (Mar 1, 2005). "Quadrasteer Off Course". Wards Auto World. Retrieved 2010-06-1
7. http://en.wikipedia.org/wiki/Steering_ratio
8. http://www.cdxetextbook.com/steersusp/steer/boxesColumns/variablesteer.html
9. http://www.zakgear.com/Rack.html
10. http://auto.howstuffworks.com/steering.htm