Cost Effective Design of Variable Steering Ratio with Power Assist

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Abstract - *The steering ratio of rack and pinion mechanism is the ratio of the number of degrees turned at the steering wheel to the number of degrees of deflection of the wheel(s) as a result. Most of the vehicles use the fixed ratio steering mechanism. However, requirement of more effort by the driver towards the lock positions is an inherent disadvantage of the fixed ratio system. To overcome this, variable-ratio steering is used. The ratio is made variable by changing the shape of the teeth on the rack. The space between the teeth is smaller at the centre of the rack and becomes larger as the pinion moves down the rack. Effort needed to turn the wheels stays approximately the same throughout the whole range of movement. In this paper a variable steering ratio mechanism has been designed 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 is incorporated in the design. The methods available so far for manufacturing of variable-pitch racks are expensive and require special tooling for the manufacture of each tooth. Hence, it is proposed that gear box of Bajaj-super may be used to vary the gearing ratio. These scooters are being phased out from the market and therefore, their gear box can be utilised in variable steering ratio mechanism. The processes involved in the manufacture of these gears are standard ones and hence cost effective. It is concluded that variable steering ratio mechanism can be helpful but only if power assist is provided with it.*

Key Words: *Variable ratio steering mechanism, power assist, steering wheel, rack & pinion steering.*

1. INTRODUCTION

The steering system of a vessel or vehicle has three main purposes: to allow the driver have control over the trajectory of the vehicle with minimal physical effort, to provide feedback for minimizing the error between the actual path and the desired path of the vehicle and to prevent the transmission of road shocks to the hands of driver by absorbing major portion of them. The steering gear transmits the driver's steering inputs to the steering linkage that turns the wheels with a mechanical advantage. The two most common steering gears are: rack and pinion and recirculating ball type.

1.1 Rack and Pinion Steering Gear

Rack-and-pinion steering gear is the most common and simple mechanism. This gear set is enclosed in a metal tube. It has a small pinion (gear wheel) at the base of the steering shaft. Its teeth mesh with a straight row of teeth on a rack - a long transverse bar. When the pinion is turned by turning the steering wheel, it makes the rack move from side to side. The ends of the rack are coupled to the road wheels by tie rods. The rack-and-pinion gear set converts the rotational motion of the steering wheel into the linear motion and provides a gear reduction. However the rack and pinion assembly is not adjustable and requires replacement once it wears out.

1.2 Recirculating Ball type Steering Gear

The recirculating ball steering gear consists of a worm gear at the end of steering rod. A nut is mounted on the worm gear by means of two sets of ball bearings. The ball bearings reduce the friction between the worm and the nut and greatly reduce the wear as they recirculate through the gear as it turns. They also reduce slop in the gear. The nut has teeth on outside that mesh with the teeth on a worm wheel sector, on which is further mounted the drop arm. During the turning of steering wheel, the balls in the worm roll which causes the nut to travel along the worm length. The nut movement results in turning of wheel sector that actuates the link rod through the drop arm, thus producing the desired steering of the wheels. There is a steering wheel play and it is adjustable, usually by a slotted bolt with a securing nut mounted on top of the housing.

The perfect steering is achieved when all the four wheel roll perfectly under all conditions of running. Perfect rolling occurs when the axes of the front wheels meet the axes of rear wheels at one point. There are two types of steering mechanism: Davis steering mechanism & Ackermann steering mechanism.

1.3 Davis Steering Mechanism

The Davis steering gear is a mathematically accurate mechanism that has two sliding pairs.

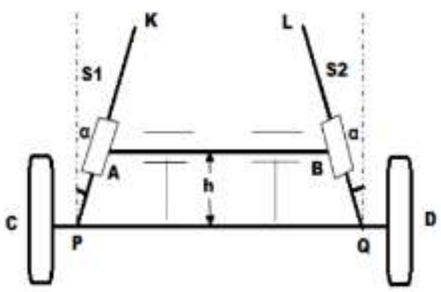

Fig 1: Davis Steering Mechanism

It consists of two arms PK& QL fixed to the stub axles PC and QD to form two similar bell crank levers CPK and DQL pivoted at P & Q respectively. A cross link or track arm AB, constrained to slide parallel to PQ is pin-jointed at its ends to two sliders. The sliders S_1 and S_2 are free to slide on the links PK and QL respectively.

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

Where w= distance between the pivots of front axle, l=wheel base. The main drawback of Davis mechanism is the wear & tear problem that causes it to become inaccurate after certain time.

1.4 Ackermann Steering Mechanism

Ackermann steering geometry does away with the need of tracing out circles of different radius by wheels on the inside and outside of a turn. The intention of Ackermann geometry is to avoid the need for tyres to slip sideways when following the path around a curve. Co-centric circle is the geometric solution to this problem. Although the system is more complex, it enhances controllability by avoiding large inputs from road surface variations being applied to the end of a long lever arm. Ackermann steering gear consists of four link mechanism PABQ having four turning pairs. Two equal arms PA and QB are fixed to the stub axles PC and QD to form two similar bell crank levers CPA and DQB pivoted at P and Q respectively.

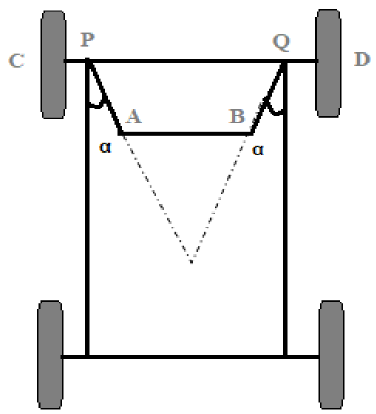

Fig 2: Ackermann Steering Gear

A cross link AB is pin-jointed at the ends to the two bell-crank levers. During the straight motion of the vehicle, the gear is in the mid-position with equal inclination of the arms PA and QB with PQ. The cross link AB is parallel to PQ in this position.

An Ackermann gear fulfils the fundamental equation of correct gearing only in three positions. The three positions of correct gearing are:

1. When the vehicle moves straight,
2. When the vehicle moves at a correct angle to the right and
3. When the vehicle moves at a correct angle to the left.

In all the other positions, pure rolling is not possible due to slipping of the wheel. 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 maneuvers. Ackermann type of steering geometry ensures consistent and smoother ride and prevents the slipping of tires during cornering. Having a high Ackerman factor is useful in taking tight corners at a relatively lower speed.

1.5 Variable Steering Ratio

A variable-ratio steering system uses different ratios on the rack, in a rack & pinion steering system. The space between the teeth is smaller at the centre of the rack and the space becomes larger as the pinion moves down the rack. Higher ratio is present in the in the middle of the rack which becomes lower when the steering wheel is turned towards the lock position. This makes the steering less sensitive, when the steering wheel is close to its centre position and makes it harder for the driver to oversteer at high speeds. Towards the lock position the wheels begin to react more to the steering input.

A disadvantage of a fixed-ratio system is that towards the lock positions, more effort is needed by the driver. This is because of the reduction in the angle of the steering arms that reduces the effective length, and which further reduces the leverage on the wheels. To overcome this variable ratio steering is used in which the mechanical advantage increases progressively as the steering moves away from the straight-ahead position. As the pinion turns, and moves on the rack, the gear contact point between the pinion, and the teeth on the rack, changes. This changes the effective diameter of the pinion and thus for the same amount of steering wheel rotation, the rack moves a shorter distance near the ends of the rack than near the centre. Effort needed to turn the wheels stays approximately the same throughout the movement.

2. CONCEPT & EXPERIMENT

The driver needs lower steering ratio at highways and higher steering ratio in busy city streets. In this paper a system has been presented that gives the steering ratio as per the needs of the driver.

In the construction of this mechanism, few external teeth gears with different ratios have been used. Some of the gears are arranged on the steering shaft and remaining on the pinion shaft in such a way that the required ratio is obtained by meshing them and selecting them at the time.

The whole assembly is then mounted in a proper iron fixture with the help of bearings so that the relative movement of shafts can be maintained. However for demonstration purpose wood fixture is used as it is light weighted. Now this whole assembly provides two shafts, steering wheel is fitted on one and pinion shaft is fitted on other. The whole set up is mounted on a wooden board so that the steering wheel and pinion shaft can be attached to the respective shafts.

Tata Nano Steering Mechanism and mesh type gearbox of Bajaj Super are used for the fabrication of variable steering ratio mechanism. 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.

3. RESULTS & DISCUSSIONS

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

The above table reveals that by successive gears 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.

By using the variable steering ratio quick steering at higher speeds can be achieved as different ratios offer us the freedom to choose by how much we want to steer. The above proposed assembly is light weight & economic and can be easily installed in passenger cars. The whole assembly is also ergonomic in design. However variable steering ratio mechanism can be helpful only if power assist is provided with it because of the following reasoning.

We need to increase the transmission ratio because for one revolution of steering wheel, we need more than one revolution of the shaft on which the pinion is attached. Assuming that the idler gears and the other gear assembly do not consume any power (which is a reasonable assumption given the very slow motion of the whole assembly), the energy or power on the shaft containing steering wheel must be completely transmitted to the shaft containing pinion.

$$T_s w_s = T_p w_p,$$ where

T_s : Torque on steering wheel side

w_s : Angular motion of steering wheel side

T_p : Torque on pinion side

w_p : Angular motion of pinion side

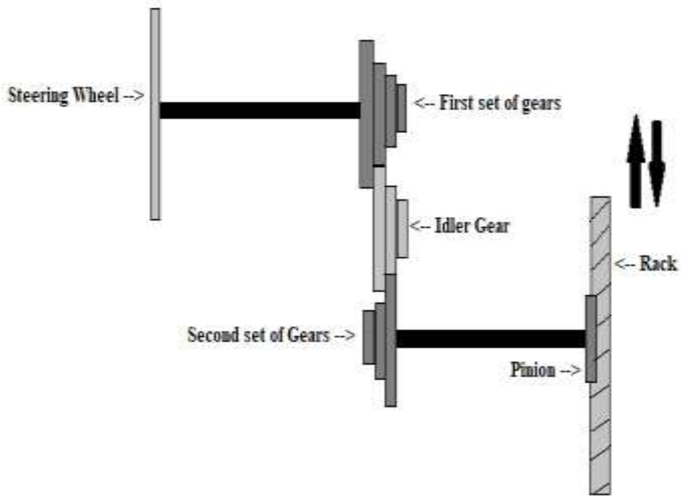

Fig 3: Schematic diagram of proposed design

4. CONCLUSIONS

The following conclusions can be drawn from the present study:

A. Engagement of 1st gear increases the steering ratio to 9.92:1

B. Engagement of 2nd gear increases the steering ratio to 7.20:1

C. Engagement of 3rd gear increases the steering ratio to 4.96:1

D. Engagement of 4th gear increases the steering ratio to 3.52:1

E. 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

F. 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.

5. REFERENCES

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