Design and Development of Four-Wheel Steering for All Terrain Vehicle (A.T.V)

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Abstract – *It is evident and factual that most of the vehicles exercises two-wheel steering mechanism as their main handling systems. However, the efficiency of the two-wheel steering vehicle is proven to be lower when compared to four-wheel steering vehicles. Four-wheel steering system can be implemented in the vehicles to improve the steering response and stability of the vehicle while cruising at certain speed and to decrease the turning radius at low speeds effectively. All-Terrain vehicles are those which see a wider and potential platform in off roading. So, it is evident that incorporating the four wheel steering system in an ATV, would increase the maneuverability of the vehicle in rough terrains.*

***Key Words*: Four-Wheel Steering, All-Terrain Vehicle (A.T.V), Transfer Shaft, Drive Shaft, Turning Radius**

1.0 INTRODUCTION

An all-terrain vehicle (ATV), also known as a quad bike, , or quadricycle is defined by the American National Standards Institute (ANSI) as a vehicle that travels on low-pressure tires, with a seat that is straddled by the operator, along with steering wheel for steering control. The rider sits on and operates these vehicles like a motorcycle, but the extra wheels give more stability at a lower speed. Although equipped with three or four-wheel, six wheels exist for the specified application.

The name itself specifies that it is an All-Terrain Vehicle, meaning it can be driven almost on all surfaces including concrete roads, desert areas, rugged terrains, grasslands, etc. ATVs are designed to handle all types of roads and their problems like bumps, dips, hills, etc. they are designed to give the convenience of driving around everywhere and reaching even the remotest areas inaccessible to other vehicles, which is their best benefit. There are three types of four-wheel steering systems in the market today:

1. Mechanical 4 Wheel Steering (WS)
2. Hydraulic 4 Wheel Steering (WS)
3. Electro/hydraulic 4 Wheel Steering (WS)

Considering the Mechanical 4WS, it does not use any kind of hydraulic or electric assist. It works on the basis of pinions and gears. In general, it is steering angle sensitive and not sensitive to the speed of the vehicle traveling.

In an active four-wheel steering system, each of the four wheels turn simultaneously when the driver steers. In an active four-wheel steering system, the rear wheels are steered by control units and actuators. The rear wheels generally cannot turn as quick as the front wheels. However, the entire system can be reconfigured to switch off the rear steer if required and enable to steer only the front wheels.

At low speeds the rear wheels turn opposite to the front wheels, reducing the turning radius, sometimes critical for vehicles with a large wheelbase, while at higher speeds both front and rear wheels turn alike (electronically controlled), so that the vehicle may change position with less yaw and improved build-up of the lateral acceleration, enhancing straight-line stability. Four-wheel steering has seen its effective existence in controlling the turning of vehicles precisely, also it increases the flexibility of driving in a complex environment. This will allow users to easily access congested areas and use very little space for turning.

1.1 Literature Survey

Mr.Lohith [1] et al developed the four wheel steering system model which was built using ADAMS software and simulations carried out to know the turning radius and maneuverability. Four wheels steering physical model was built considering same stub axle for front and rear. CRC test was conducted to analyze maneuverability of the model. Turning radius comparison were made between the physical model and the ADAMS model.

Mr Lee, A.Y., [2] Mobile robot driving mechanism can be classified into three types; skid steering, Ackerman and axle articulated. Skid steering driving mechanism which uses differential drive concept is suitable for either tracks or wheels robot. Most of the robot structures in the literature were made of steel, aluminium or plastic.

1.2 Methodology

We are adopting the method of using drive shaft mechanism for the purpose of power delivery to the rear wheels via a two stroke motor. The front wheels will be the dead wheels. We are incorporating steering columns for both front and rear axles. For the steering, a steering wheel is used which eases steering motion. A shaft with bevel gear mounted on ends of the steering rod and a transfer shaft. This reverses the motion of the steering so that the opposite direction of steer is achieved at the rear end. A Universal joint can be connected for freedom of movement and for stress free steering usage. The steering column which is placed between the front wheels needs to transmit steering motion to the steering column placed between the rear wheels. For that, a transfer shaft specially made to transmit the turning motion to the rear wheels is incorporated. As there is an implementation of universal joints at the ends of drive shaft, steering the vehicle will be very easy.

We will be using a rectangular frame which will be MS cold rolled due to its light and compact setup. We are using Arc welding to weld the side members and cross members to the chassis. This type of welding is better in all ways and provides more strength at the weld joints. No modifications will be done to the engine, but the chassis will get slight tweaks. The front end will accommodate the two wheels and suspension setup. The suspension setup we are incorporating will be a double wishbone suspension for all the four wheels. The engine will be placed towards the rear side of the vehicle making it a rear wheel drive as it is compact and produces enough power to move the vehicle around. By doing this, we can achieve a fully-fledged four wheel steering system on an All- Terrain Vehicle. The wheel diameter of the wheel that will be used is 8 inches. The wheel base of the ATV being 1140 mm, wheel trackof 1125 mm and a ground clearance of 170 mm, the ATV is fully prepped. We have calculated the steering mechanism based on correct four wheel steering mechanism or Ackerman steering mechanism. The front wheels tend to actuate in opposite direction to that of the rear wheels. That is, when the front wheels turn towards right the rear wheels turn towards left by a decent margin. The steering columns are connected by means of a shaft with two bevel gears at each ends for reversing the driving mechanism of the front wheels.

2.0 Calculation for ATV – 4WS

This project deals with Ackermann Steering mechanism and Correct Four Wheel Steering mechanism.

2.1 For Ackermann Steering Mechanism.

Ackermann steering mechanism deals with the correct steering angle of the vehicle on the curved path, where the front wheels only turn at certain angle.

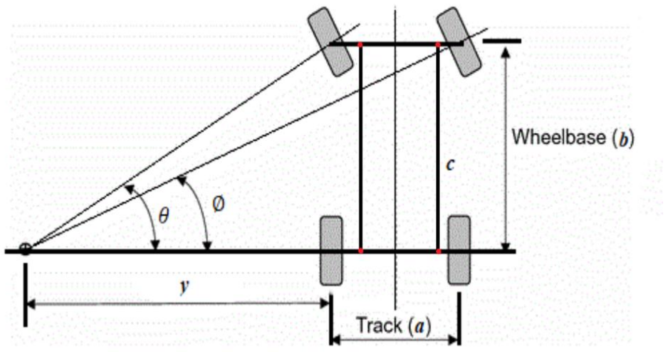

Figure 2.1 Ackermann steering mechanism

This is the diagram for the Ackermann steering mechanism, where

Ø = the angle of the outer wheel

θ = the angle of the inner wheel

b = wheel base of the vehicle

a = wheel track of the vehicle

c = the distance between the front axle and the rear axle

R = turning radius of the vehicle

y = the distance between the point of concurrence and the rear inner wheel centre.

2.1.1 For the outer wheel

$$\cot \emptyset = \frac{y+c}{b}$$

$$\frac{1}{\tan \emptyset} = 1.851$$

$$\emptyset = 28.38^{o}$$

R_{OF} (Outer Front) = $\frac{b}{\sin \emptyset} + \left(\frac{a_1 - c}{2}\right)$

$= \frac{1140}{\sin(28.38)} - \left(\frac{1125-914}{2}\right)$

R_{OF} = 2503.89 mm = **2.5039 m**

R_{OR} (Outer rear) = $\frac{b}{\tan \emptyset} + \left(\frac{a_2 - c}{2}\right)$

R_{OR} = 2215.64 mm = **2.2156 m**

Turning radius at Front = $\frac{1.5475+2.5039}{2}$

= 2.025 m

2.1.2 For the inner wheel

$$\cot\emptyset - \cot\theta = \frac{c}{b}$$

$$\cot\theta = 1.851 - \frac{914}{1140}$$

$$\cot\theta = 1.05$$

$$\frac{1}{\tan\theta} = 1.05$$

$$\theta = 43.6^{o}$$

R_{IF} (Inner Front) = $\frac{b}{\sin\theta} - \left(\frac{a_1 - c}{2}\right)$

= $\frac{1140}{\sin(43.6)} - \left(\frac{1125-914}{2}\right)$

R_{IF} = 1547.5 mm = **1.5475 m**

R_{IR} (Inner rear) = $\frac{b}{\tan\theta} - \left(\frac{a_2 - c}{2}\right)$

R_{IR} = 1091.61mm = **1.0916 m**

Turning radius at Rear = $\frac{1.0916+2.2156}{2}$

= 1.653 m

2.2 For Negative four wheel steering mechanism.

In a negative four wheel steering mechanism the vehicle wheels at front when rotated towards right, the rear wheels turns towards left making the vehicle rotate in a very small space, this making the vehicles turning radius is less compared to normal vehicles.

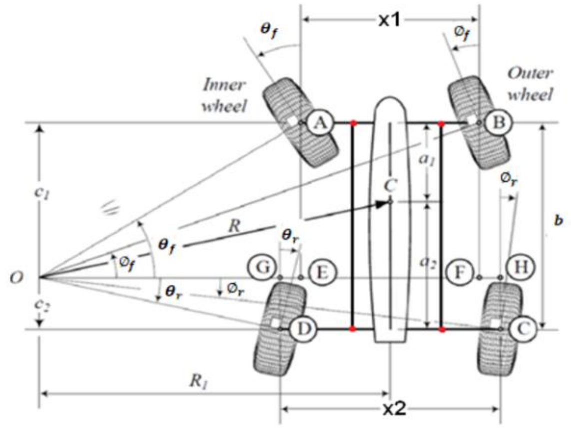

Figure 2.2 Correct Four wheel steering mechanism

This is the line diagram for correct four wheel steering mechanism, where

R = radius of the vehicle from the point CG to the Concurrence point

R_1= Distance b/w the concurrence point and the axis of the vehicle

$\emptyset_f$ = Angle of the outer front wheel

$\emptyset_r$= Angle of the outer rear wheel

θ_f= Angle of the inner front wheel

θ_r= Angle of the inner rear wheel

y = wheel track of the vehicle at rear

c = wheel track of the vehicle at front

C = Centre of Gravity of the vehicle

b = Wheel base of the vehicle

a_1 = Distance b/w CG point and the front axle

a_2 = Distance b/w CG point and the rear axle

O = Point of Concurrence

c_1 = Distance b/w the point of concurrence and the front axle

c_2 = Distance b/w the point of concurrence and the rear axle.

2.2.1 For outer wheels

$$\cot\emptyset = \frac{y_1 + t_1}{c_1}$$

$$\cot\emptyset = 1.8960$$

$$\frac{1}{\tan \emptyset} = 1.8960$$

$$\emptyset = 27.80^{o}$$

R_{OF} (Outer front) = $\dfrac{c_1}{\sin \emptyset} + \left(\dfrac{x_1 - t_1}{2}\right)$

R_{OF} = 2280.022 mm = **2.2800 m**

R_{OR} (Outer rear) = $\dfrac{c_2}{\tan \emptyset} + \left(\dfrac{x_2 - t_2}{2}\right)$

R_{OR} = 939.600 mm = **0.93960 m**

2.2.2 For inner wheels

$$\cot \emptyset - \cot \theta = \frac{t_1}{b}$$

$$\cot \theta = 1.8960 - \frac{914}{1020}$$

$$\cot \theta = 0.99999$$

$$\frac{1}{\tan \theta} = 0.99999$$

$$\theta = 45^{o}$$

R_{IF} (Inner front) = $\dfrac{c_1}{\sin \theta} - \left(\dfrac{x_1 - t_1}{2}\right)$

R_{IF} = 1349.49 mm = **1.34949 m**

R_{IR} (Inner rear) = $\dfrac{c_2}{\tan \theta} - \left(\dfrac{x_2 - t_2}{2}\right)$

R_{IR} = 277 mm = **0.277 m**

Therefore, the turning radius at the front and rear wheels would be

Front Wheels $= \dfrac{1.3494+2.2800}{2}$ = **1.8147 m**

Rear Wheels $= \dfrac{0.277+0.93960}{2}$ =**0.6083 m**

3.0 Mechanical Design of ATV

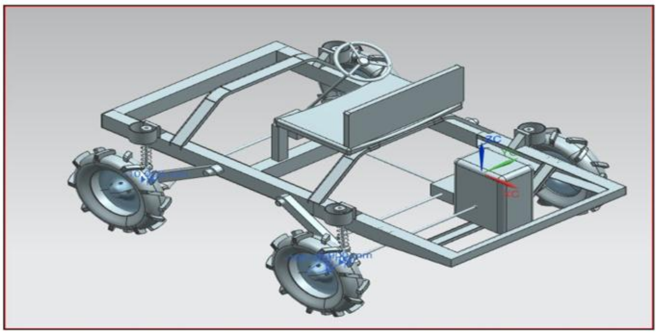

Figure 3.1 Isometric view of ATV – 4WS

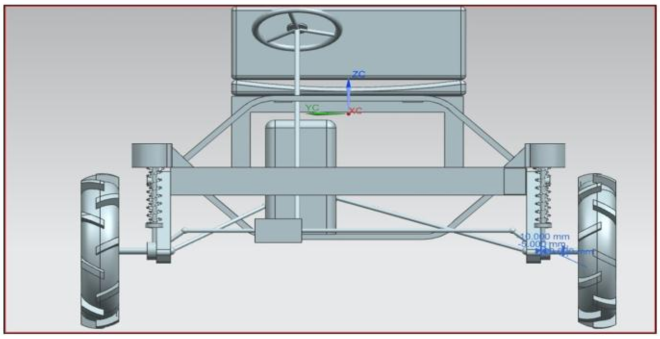

Figure 3.2 Front view of ATV – 4WS

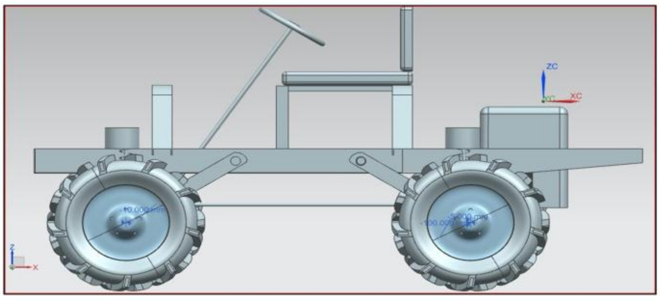

Figure 3.3 Left view of ATV – 4WS

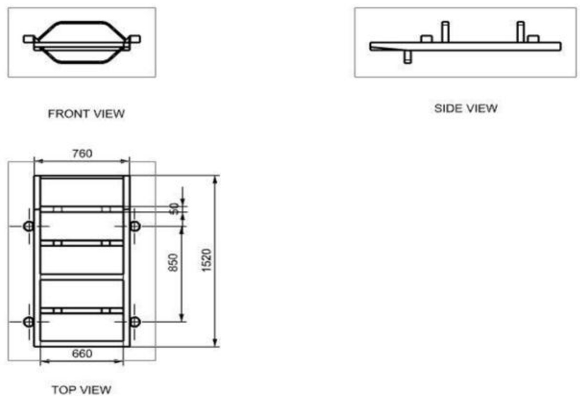

Figure 3.4 Draft layout of ATV – 4WS

The above figures illustrates the mechanical system design of ATV – 4WS. The main components used are MS tubes, support frames for chassis, wheels, suspension system, steering shat, steering wheels, power train and wheel support frames.

The outer frames of the chassis are built or designed using MS plates where the ends of the tubes are welded. The centre support frames are also MS plates which are bent at an angle to provide rigid supports to the outer frames. The steering shaft is coupled to the main wheel shafts using bevel gears. Universal joints are provided to provide flexible and smooth steering functions. The wheels are provided with suspension to provide cushioning and damping effects to the chassis frame. The wheel assembly along with suspension systems are mounted on the outer frame of the chassis by strong bars.

4.0 Development of ATV – 4WS

4.1 Chassis

Figure 4.1 Chassis layout.

Chassis is defined as a framework or a support which is developed to provide a strong and rigid support to the body and other peripherals of a motor vehicle. It is considered as one of the vital parts of the vehicle. The combination of components like frames, suspension, steering shafts are combined and called as chassis. The chassis is constructed by Mild Steel cold rolled hollow rectangular shaped material for better finish and strength. The rear half of the chassis is of an auto rickshaw and the above mentioned material is used for making the front half. The double wishbones are also welded on to the chassis. The steering columns, the transfer shaft and the suspension supports also are welded to the chassis.

4.2 Engine

Figure 4.1 Engine.

A Two-stroke (or two-cycle) engine is a type of internal combustion engine which completes a power cycle with two strokes (up and down movements) of the piston during only one crankshaft revolution. This is in contrast to a "four-stroke engine", which requires four strokes of the piston to complete a power cycle during two crankshaft revolutions. In a two-stroke engine, the end of the combustion stroke and the beginning of the compression stroke happen simultaneously, with the intake and exhaust (or scavenging) functions occurring at the same time. Two-stroke engines often have a high power-to-weight ratio, power being available in a narrow range of rotational speeds called the "power band". Compared to four-stroke engines, two-stroke engines have a greatly reduced number of moving parts, and so can be more compact and significantly lighter. Engine is the main component of the vehicle.

4.3 Steering

Figure 4.3 Steering (Rack and Pinion Assembly)

A Rack and pinion is a type of linear actuator that comprises a circular gear (the *pinion*) engaging a linear gear (the *rack*), which operate to translate rotational motion into linear motion. Driving the pinion into rotation causes the rack to be driven linearly. Driving the rack linearly will cause the pinion to be driven into a rotation. For example, in a rack railway, the rotation of a pinion mounted on a locomotive or a railcar engages a rack between the rails and forces a train up a steep slope. For every pair of conjugate involute 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 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. 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. The objective of the steering system is to provide max directional control of the vehicle and provide easy maneuverability of the vehicle in all types of terrains with appreciable safety and minimum effort.

The response from the road must be optimum such that the driver gets. 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.

4.4 Suspension

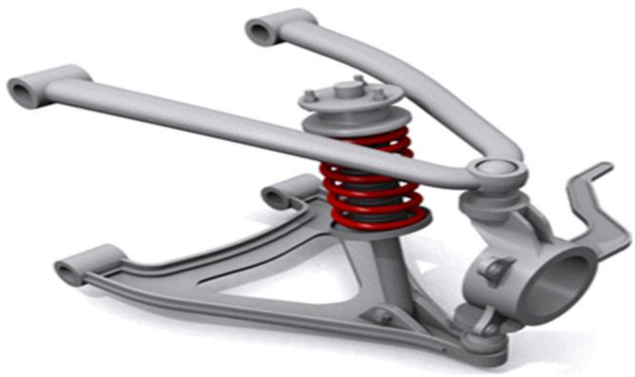

Figure 4.4 Suspension

A double-wishbone is an independent suspension design that can be found at the front, rear, or all four wheels. In this context, ―independent means that a single wheel's movement is not affected by the other three wheels. In other words, it's free to move (somewhat) independently of the chassis.

This design offers several advantages, specifically in high performance on- and off-road environments. The key benefit is that, unlike a similar MacPherson strut setup, a double wishbone design doesn't significantly affect wheel camber with suspension travel. On modern systems, the upper and lower control arms typically use ball joints to secure the spindle/hub assembly. The arms are then connected to the vehicle chassis or body, where they're allowed to pivot. On drive wheels, the axle half-shafts are joined to the differential and hub flanges via CV or U-joints, permitting each wheel to move up and down. It also allows side-to-side steering movement in front-wheel-drive applications. A shock absorber (damper) is usually positioned between the upper and lower control arms to suppress suspension bounce. Between the outboard ends of the arms is a knuckle. The knuckle contains a kingpin for horizontal radial movement in older designs, and rubber or trunnion bushings for vertical hinged movement. In newer designs, a ball joint at each end allow for all movement. Attached to the knuckle at its center is a bearing hub, or in many older designs, a spindle to which the wheel bearings are mounted.

4.5 Transfer and Drive Shafts

4.5.1 Transfer Shaft

Figure 4.5.1 Transfer shaft developed.

We accommodate a specially made shaft that can transfer steering motion that is derived from the front wheels to be transferred to the rear wheels but giving out opposite direction of steer. This transfer shaft is fitted with bevel gear at one end for the steering motion to be transmitted and a universal joint at the other end to avoid shocks. As torque carriers, transfer shafts are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, while avoiding too much additional weight as that would in turn increase their inertia. To allow for variations in the alignment and distance between the driving and driven components, drive shafts frequently incorporate one or more universal joints, jaw couplings, or rag joints, and sometimes a splined joint or prismatic joint.

4.5.2 Drive Shaft

Figure 4.5.2 Drive shaft.

A drive shaft or propeller shaft is a piece of an automobile which takes power from the engine and delivers to the wheels. A drive shaft has to be strong enough to absorb the torque of the engine and lightweight to reduce the overall weight of the vehicle. A drive shaft, driveshaft, driving shaft, tail shaft (Australian English), propeller shaft (prop shaft), or Cardan shaft is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them. A drive shaft should be perfectly balanced and should spin equal to the torque coming out of the engine and the transmission for a smooth driveline performance.

We are using drive shafts to transfer engine power to the rear wheels. As torque carriers, drive shafts are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, while avoiding too much additional weight as that would in turn increase their inertia. To allow for variations in the alignment and distance between the driving and driven components, drive shafts frequently incorporate one or more universal joints, jaw couplings, or rag joints, and sometimes a splined joint or prismatic joint. Drive shaft is used to connect transmit power from the engine to the rear wheels so the vehicle is in motion. This is connected to the engine and the rear wheel hub by a locking mechanism for the rotation of the shaft and transmit the power from the engine to the rear wheels.

4.6 Other Components of ATV – 4 WS

4.6.1 Brake

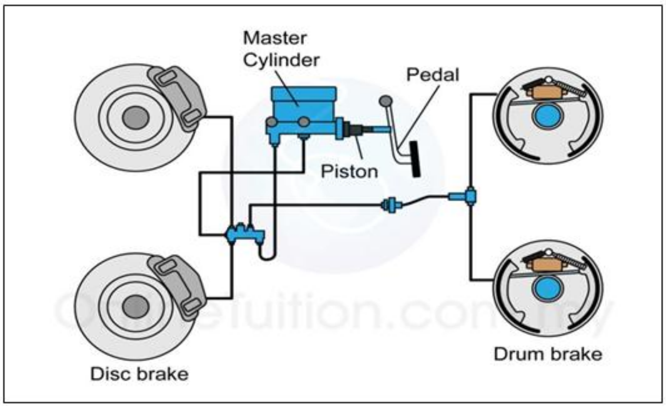

Figure 4.6.1 Hydraulic braking system

We are using drum brakes as the auto wheels could only accommodate drum brake type. A drum brak**e** is a brake that uses friction caused by a set of shoes or pads that press outward against a rotating cylinder-shaped part called a brake drum. The term *drum brake* usually means a brake in which shoes press on the inner surface of the drum. When shoes press on the outside of the drum, it is usually called a *clasp brake*. Where the drum is pinched between two shoes, similar to a conventional disc brake, it is sometimes called a *pinch drum brake*, though such brakes are relatively rare. A related type called a band brake uses a flexible belt or "band" wrapping around the outside of a drum.

4.6.2 POS Bearing:

Figure 4.6.2 POS 12mm bearing.

We are using POS bearings to be placed on the bolt welded onto the stub. It is to provide freedom of movement of the wheels. The other end is fitted to the double wishbone setup. A **rod end bearing**, also known as a **heim joint** (N. America) or **rose joint** (U.K. and elsewhere), is a mechanical articulating joint. Such joints are used on the ends of control rods, steering links, tie rods, or anywhere a precision articulating joint is required, and where a clevis end (which requires perfect 90-degree alignment between the attached shaft and the second component) is unsuitable.

4.6.3 Bevel Gears

Figure 4.6.3 Bevel gears.

We are using bevel gears for transmitting steering rotation to the transfer shaft. The gears join almost perpendicular to each other. **Bevel gears** are gears where the axes of the two shafts intersect and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are most often mounted on shafts that are 90 degrees apart, but can be designed to work at other angles as well. The pitch surface of bevel gears is a cone.

4.6.4 Universal Joint

Figure 4.6.4 Universal joint.

We are adopting universal joints at the end of the transfer shaft and at the end of the steering rod for flexibility and smooth function of steering. A **Universal joint** (**universal coupling**, **U-joint**, **Cardan joint**, **Spicer** or **Hardy Spicer joint**, or **Hooke's joint**) is a joint or coupling connecting rigid rods whose axes are inclined to each other, and is commonly used in shafts that transmit rotary motion. It consists of a pair of hinges located close together, oriented at 90° to each other, connected by a cross shaft. The universal joint is not a constant-velocity joint.

A universal joint is a mechanical device that allows one or more rotating shafts to be linked together, allowing the transmission of torque and/or rotary motion. It also allows for transmission of power between two points that are not in line with each other.

5.0 Observation

Fig 5.0 : Four Wheel ATV Fig 5.1 Suspension system

Fig 5.2 Wheel mount design

Fig 5.3 Wheel mount design

The above figures shows the layout development of four wheel ATV.

With reference to the calculations comparing Ackerman Steering Mechanism principle with the Negative Four-Wheel Steering Mechanisms, we have proven that the turning radius of both inner and outer wheels are reduced by a significant amount.

From 2.1. Ackerman Steering Mechanism

The obtained value for Outer front wheel: 2.5039 m

The obtained value for Inner front wheel: 1.5475 m

Turning radius at Front: 2.025 m

The obtained value for Outer rear wheel: 2.2156 m

The obtained value for Inner rear wheel: 1.0916 m

Turning radius at Rear: 1.653 m

From 2.2. For Negative four wheel steering mechanism.

The obtained value for Outer front wheel: 2.2800 m

The obtained value for Inner front wheel: 1.34949 m

Turning radius at Front: 1.8147 m

The obtained value for Outer rear wheel: 0.93960 m

The obtained value for Inner rear wheel: 0.277 m

Turning radius at Rear: 0.6083 m

From the above calculations and the observations from the developed Four-wheel steering mechanism, it is found that the turning radius of the vehicle is reduced by 34.13%

6. CONCLUSIONS

Adopting this technology on an ATV will help farmers to access remote areas of the field where tractors or other earth moving equipment's cannot ply. It is cheap so that even poor farmers, who cannot afford a tractor, can use this ATV for agricultural purposes. The four-wheel steer technology can be adopted with a very low budget. This will also take off the burden from small scale farmers. Applying this four wheel steering system to the ATV will be useful in remote areas and in congested places tomanoeuvre it. This gives more advantages for the farmers to use this ATV instead of the conventional tractors or any other heavy machinery in remote areas. The advantage of this ATV is that this can be attached with attachments for ploughing and scrapping, etc. at the rear of the ATV and can be used for agricultural purposes.

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