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Integrated Steering Systems to Enhance Manoeuvrability: Technical Note

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ABSTRACT:

Most vehicles today employ conventional steering system where the front wheels are solely responsible for steering the vehicle, due to this the rear wheels remain dependent of the front wheels in the dynamic condition which is not allowing the vehicle to reach its maximum potential. On the other hand, in a four-wheel steering system the rear wheels along with the front wheels steer the vehicle improving its manoeuvrability. Four wheels steering also produces better acceleration as power is distributed to all the four-wheels enhancing the net traction and reducing the overall rolling resistance. Vehicles today are designed to under-steer a little with a steering ratio ranging between 14:1and 22:1, this phenomenon fails in few scenarios where it takes longer to manoeuvre a vehicle in case of lane emergencies. Implementing in-phase and counter-phase steering mechanisms in a vehicle allow sharper turn, reduces tire wear and improves the overall manoeuvrability of the vehicle. Factors like steering torque, turning angle and velocity of the vehicle are taken into consideration for devising a proper method to shift between different steering modes. The input from steering angle and torque at a certain speed, allows the vehicle to choose between the crabs, parallel or counter steering mechanism during a turn for best performance. Thereby, integrating these mechanisms in a single vehicle would invariably stabilize and provide a better control to the driver in high as well as slow speed conditions.

KEYWORDS:

Under-steer; Over-steer; Sharp turns; Steering torque; Turning angle

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NOMENCLATURE:

L - Wheelbase length.
T - Track width.
A - Axial distance of center of gravity from front axle.
B - Axial distance of center of gravity from the rear axle.
R - Turning radius of the vehicle.
$\delta i/\delta if$ - Angle of the inner front wheel during turning.
$\delta o/\delta of$ - Angle of the outer front wheel during turning.
δir - Angle of the inner rear wheel during turning.
δor - Angle of the outer rear wheel during turning.

1. Introduction

Four wheel steering systems have enhanced the vehicle's manoeuvrability effectively [1-2]. This can further be improved by adding different mechanisms of 4 wheel steering at various speeds. Steering mechanisms are classified into an in-phase and counter phase mechanism. When the vehicle is turning at low-speed and has to cover a corner of short radius of turning, the counter-phase mechanism can be used to turn the vehicle effectively. During high-speed turning when a larger radius of turn has to be covered, the in-phase mechanism can be employed to turn. This means that counter-phase mechanism can be used to give us sharper turns whereas in-phase mechanism is used to cover larger turning radius at high-speed [3]. This change in mechanism during cornering can be achieved by employing a steering angle sensor and a vehicle speed sensor to collect the angle by which the front wheels are steered and the vehicle's speed [4-5]. This data is used by the Arduino which has already been programmed to use the input data to select the mechanism required to turn in that condition according to the speed and the angle of steer runs by the servo motor to turn the rear wheels according to the initial conditions. In this manner, the steering of all the four wheels can be controlled, and the manoeuvrability of the vehicle can be improved.

A vehicle runs at a slow speed mainly during sharp turns and driving through heavily crowded areas. Hence in case of slow speed sharp turns, the vehicle automatically opts for counter steering mode which facilitates the car to turn with the least possible turning radius. At higher speeds, it is possible to control and stabilize the vehicle with the aid of in-phase steering mechanism. A vehicle experiences lane change and cornering at banks with a large radius of curvature of the road. Parallel steering mechanism efficiently manoeuvres the vehicle at these large curvatures on the road. In this paper,

2. Methodology

A bell-crank mechanism is used to steer front wheels of the vehicle. This is done to produce a 1:1 steering input ratio since it provides faster turning. It consists of a steering shaft connected to a universal joint attached to a road on whose other end is another universal joint which rotates by the rotation of the rod. The other end of the second universal joint is fixed to the bell crank lever from which tie rods are sent to the knuckle of the wheel. The rear wheels are also powered by bell crank mechanism system which is connected to a servo motor attached to a battery. The servo motor configuration with Arduino coding acts as the steering input to the system. To choose the type of steering required, a joystick is also connected to a microprocessor which translates this data and accordingly converts the signals into a mechanical function of the motor. A potentiometer is connected to the front wheel to determine the angle of rotation of the wheel from the center axis and relays it to the Arduino board. Accordingly, the motor is programmed to rotate in the rear.

3. Results and discussions

Figs. 1 to 3 show the centre of gravity, Ackermann's steering geometry for front wheel and four wheel steering respectively. Based on the vehicle with wheel base of 1.52m and track width of 1.06m, the centre of gravity can be found as,

$$B = \frac{L \times Rf}{W} = \frac{1.52 \times 45}{105} = 0.65m$$

A = 0.87m

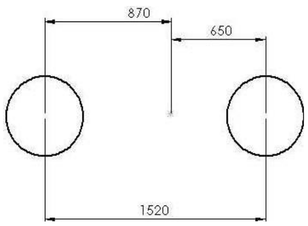

Fig. 1: Centre of gravity of the vehicle, Dimensions are in mm

Ackermann's steering:

$$cot\delta_o - cot\delta_i = \frac{t}{l} = \frac{1.06}{1.52} = 0.70$$

$\delta_o = 23°$ and $\delta_i = 31°$

$$cot\delta = \frac{cot\delta_o - cot\delta_i}{2} = 2.02, \delta = 26°$$

$$R = \sqrt{a_2^2 + l^2 cot^2\delta} = \sqrt{0.4225 + 2.31 \times 4.33}$$

$$= 3.22\text{m}$$

$$R^2 = R_L^2 + a_2^2, \quad R_L = \sqrt{3.22^2 - 0.65^2} = 3.15\text{m}$$

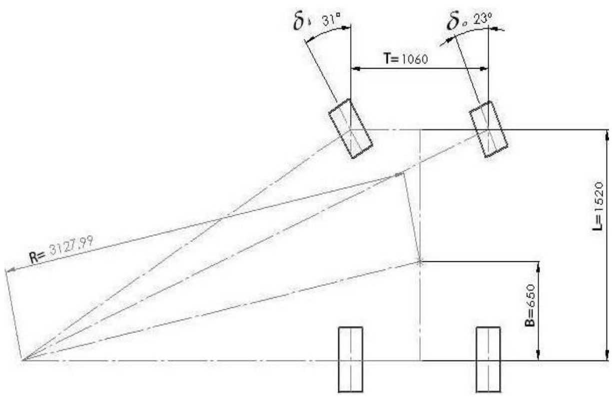

Fig. 2: Ackermann's steering geometry for front wheel steering, Dimensions are in mm

Negative Ackermann's steering:

$$tan\delta_{if} = \frac{c_1}{R_L - 0.5t}$$

$$tan\delta_{of} = \frac{c_1}{R_L + 0.5t}$$

$$tan\delta_{ir} = \frac{c_2}{R_L - 0.5t}$$

$$tan\delta_{or} = \frac{c_2}{R_L + 0.5t}$$

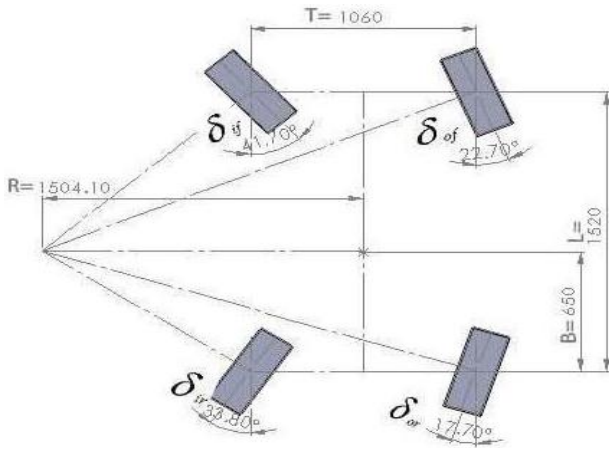

Fig. 3: Ackermann's geometry for four wheel steering vehicle, Dimensions are in mm

Fig. 4 shows the wheel assembly of vehicle with the following dimensions,

$E = 0.127m \quad B = 0.07m$

$$Steering\ torque = W \times f \times \sqrt{\frac{B^2}{8} + E^2}$$

$Front\ axle\ load = 45kg$

$Front\ steering\ torque\ on\ knuckle$
$= 450 \times 0.1\sqrt{0.02} = 10.8Nm$

$Rear\ axle\ load = 65kg$

$Rear\ steering\ torque\ on\ knuckle$
$= 650 \times 0.1\sqrt{0.02} = 9.1Nm$

$Knuckle\ torque = 9Nm$

$Steering\ arm\ length = 0.15m$

$$Load\ to\ turn\ wheel = \frac{9}{0.15} = 60N$$

$Capacity\ of\ motor = 8.5Nm$

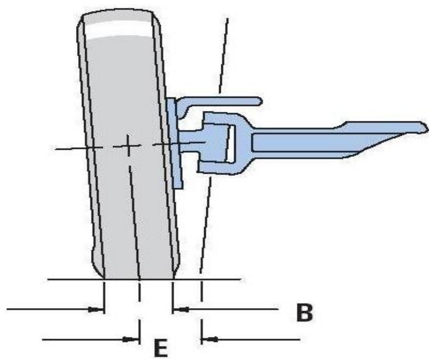

Fig. 4: Wheel assembly of the vehicle

Servo motor is selected for the steering due to a number of advantages such as low cost, smooth rotation at low speeds, no power used to a standstill, availability of high peak torque and high-speed attainment capabilities. The capacity of motor is 8.5 Nm. An Arduino (UNO) board is used to attach a LED for testing. The codes were compiled and ran. The servo motor is connected to the Arduino board which turns it according to the angle input received from the angle sensor or potentiometer. The steering angle provided at the front is noted by the potentiometer which relays the information to the board which is coded to turn the servo motor to the same amount in the rear. The sample program for Arduino system is shown in Fig. 5.

```
Void setup (){
pinMode(13,OUTPUT); // motor relay is connected here
}

Void loop (){
 analogRead(A0);//        potentiometer middle terminal here

 if (analogRead(A0)> constant){
 digitalWrite(13,HIGH);
 }
else
 digitalWrite(13,LOW);
}
```

Fig. 5: Arduino program for steering test on four wheel drive

4. Conclusion

In this paper, the four-wheel steering mechanism is used to demonstrate an integrated approach. High and low speed steering modes are designed to cope with various vehicle speeds. High-speed steering used a parallel steering mechanism and low or medium speed used an anti-parallel mechanism. Acermann's steering calculations have shown that proposed integrated deisgn approach will lead to improvements in the handling and stability of the vehicle for high and low speeds.

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