

# **DESIGN AND ANALYSIS OF BRAKE ASSISTED TORQUE STEERING SYSTEM FOR HEAVY COMMERCIAL VEHICLE TO REDUCE TURNING CIRCLE DIAMETER**

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**ABSTRACT:** Commercial vehicles are equipped with power assisted steering system in order to reduce the effort required to steer the vehicle. One of the main issues faced by the heavy duty commercial vehicles like trucks and buses is that it consumes larger space to take a turn. The limit of turning radius is decided by the government and is specified in the Indian standards. As these commercial vehicles need longer turning radius it is tedious to take turn in cities especially in traffic. Reducing the turning circle diameter (TCD) has been an increasing challenge with increase in the wheelbase of the vehicles. Lot of work has been carried out to improve the axle wheel turn angles and to optimize the Ackerman geometry of the wheels. However, there is a limitation over the improvement of TCD by increasing the wheel lock angle because tyre starts scrubbing beyond critical limit of lateral stiffness. Further improvement in TCD is only possible by using higher stiffness tyres, reducing the load, shifting the CG towards rear. Above mentioned methods reduce the amount of lateral force required to turn the vehicle. But, all the above methods mandate for compromise in either performance or vehicle features.

So our system mainly focuses on reducing the turning radius of a commercial vehicle without changing its geometry. In this work, synchronization of steering system and braking system is proposed to enhance the low speed turn ability of the vehicle. Similar to chained traction off-highway vehicles and battle Tanks, drive system is purported to assist in turning the vehicle. We, in our system introduce the concept of torque vectoring. This system is expected to reduce the TCD of the vehicle by around 5% without compromising on the other performance features. This system enables the controlled biased distribution of torque to the inner and outer wheel in cornering, by the selective application of the corresponding brakes. Our system incorporates a pneumatic, an electronic and a torque distribution unit. We were successful in reducing the turning radius of the design vehicle, such that radius, at a constant speed, reduces with time, a dynamic reduction. Using this system, it is also possible to correct the default under steer or over steer characteristics.

**KEYWORDS:** Turning circle diameter-TCD, Steering system, Torque vectoring, Over and Under steer.

## **I.INTRODUCTION**

### **PROBLEM STATEMENT:**

Turning radius has been an issue of concern for the HCV and the vehicles having long wheel base. Especially, buses in cities and the trucks in the special application find it difficult to take turns. Some buses in the city have to get to the outer edge to take the turn (U-turn) at ease also those riding in the hairpin roads. The trucks in the mine fields and similar other applications are highly concerned about the turning as the roads are very narrow and uneven. Thus our system finds a high potential in these application.

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### TORQUE VECTORING:

Torque vectoring is a method of introducing differential torque, thereby, a differential speed to the inner and outer wheel of the live axle preferably rear), during a turn. They are of two types. One is, brake based torque vectoring and the other one is clutch based torque vectoring. Stability in lateral dynamics is achieved through a torque vectoring differential.

### II. TERMINOLOGIES

- 1) TCD or Turning Circle Diameter is the diameters of the circles circumscribing the extensions on the supporting plane of mid planes of the steered wheels (the steering wheel being turned to the full lock).
- 2) TCCD OR Turning Clearance Circle Diameter is the (the steering wheel being turned to full lock)
  - a) The diameter of the smallest circle enclosing the projections onto the supporting plane of all points of the vehicle.
  - b) The diameter of the largest circle beyond which are located the projections onto the supporting plane of all the points of the vehicle.
- 3) Steering Angle is the maximum angle of turn built into a front steering mechanism
- 4) Yaw rotation is a movement around the yaw axis of a rigid body that changes the direction it is pointing, to the left or right of its direction of motion.
- 5) Yaw rate or yaw velocity of a car, aircraft, projectile or other rigid body is the angular velocity of this rotation, or rate of change of the heading angle when the aircraft is horizontal. It is commonly measured in degrees per second or radians per second.
- 6) Spin turn is a kind of turn in tractor where one of the rear wheel is locked the tractor is able rotate about that that wheel. This is also found in the wheelchair.

### III. SENSORS

- 1) A wheel speed sensor or vehicle speed sensor (VSS) is a type of tachometer. It is a sender device used for reading the speed of a vehicle's wheel rotation. It usually consists of a toothed ring and pickup.
- 2) Angle sensor detects the orientation of an applied magnetic field by measuring sine and cosine angle components with monolithically integrated magneto resistive elements. They enable angular measurements with high accuracy by an excellent linearity and temperature drift behaviour.
- 3) Yaw rate sensor is a gyroscopic device. It measures a vehicle's angular velocity around its vertical axis. The angle between the vehicle's heading and vehicle actual movement direction is called slip angle, which is related to the yaw rate.

### IV. BRAKE ASSISTED TORQUE STEERING

#### TORQUE VECTORING IN "BRAKE ASSISTED TORQUE STEERING":

Torque vectoring works better in vehicle with high torque and power. This is generally used under high speed to make a cornering at ease and stable way. But we are planning to use it at slow speed and the excess torque that creates a yaw moment which can reduce the turning radius of the heavy vehicle.

SYSTEM: Our system consist of mainly three parts

- ✓ Controller- Electronic unit
- ✓ Actuator- pneumatic unit

- ✓ Torque vectoring unit

**CONTROLLER- ELECTRONIC UNIT:**

The electronic unit is like the brain of the system. Our system consists of a feedback and feed forward control loop.

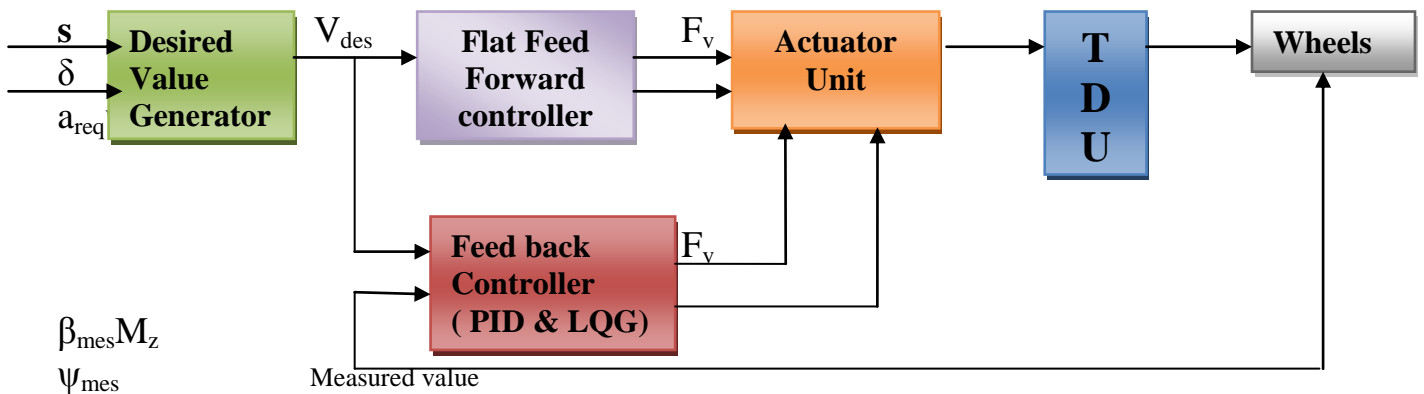


Figure 1: Layout of Controller-Electronic unit

**Desired Value Generator:**

A desired value generator gets the steering angle of the wheels  $\delta$  and the desired acceleration request  $a_{req}$  from the pedals. With these inputs the desired value generator creates favoured states (velocity, side slip angle and yaw rate) of the vehicle.

**Feed Forward Control:**

A flat feed forward controller in parallel to a combination of a PID and Linear Quadratic Gaussian (LQG) controller are calculating the desired force  $F_x$  in longitudinal direction and the desired yaw moment  $M_z$  around the vertical axis of the vehicle. The feed forward controller is used to improve the dynamics of the system.

**LQG- Linear Quadratic- Gaussian:**

The LQG reduces lateral errors due to model uncertainties and parameter variations. Disturbances like side winds are cancelled out with the LQG controller.

**PID Controller:**

The PID controller is used to cancel disturbances in longitudinal direction. In a torque distribution unit (TDU) the yaw and longitudinal commands are transferred to individual wheel torque requests  $T_{wheel}$  for the four wheels.

**ACTUATOR- PNEUMATIC UNIT:**

In our system we are using the pneumatic actuator for actuating the torque vectoring differential.

Table 1: Components of Actuator-Pneumatic Unit

S. No.	Component	Description	Quantity
1.	Tank	-	1
2.	Compressor	Solenoid actuated	1
3.	Filter	-	1
4.	DCV	5/3	1
5.	Pressure Relief Valve	-	2

**Operation of Pneumatic System:**

On receiving signal from ECU the compressor supplies the air at high pressure. The DCV decides the direction, either to the left or to the right, according to the impulse received from the angle sensor via ECU.

**Representation of the circuit in Fluidsim:**

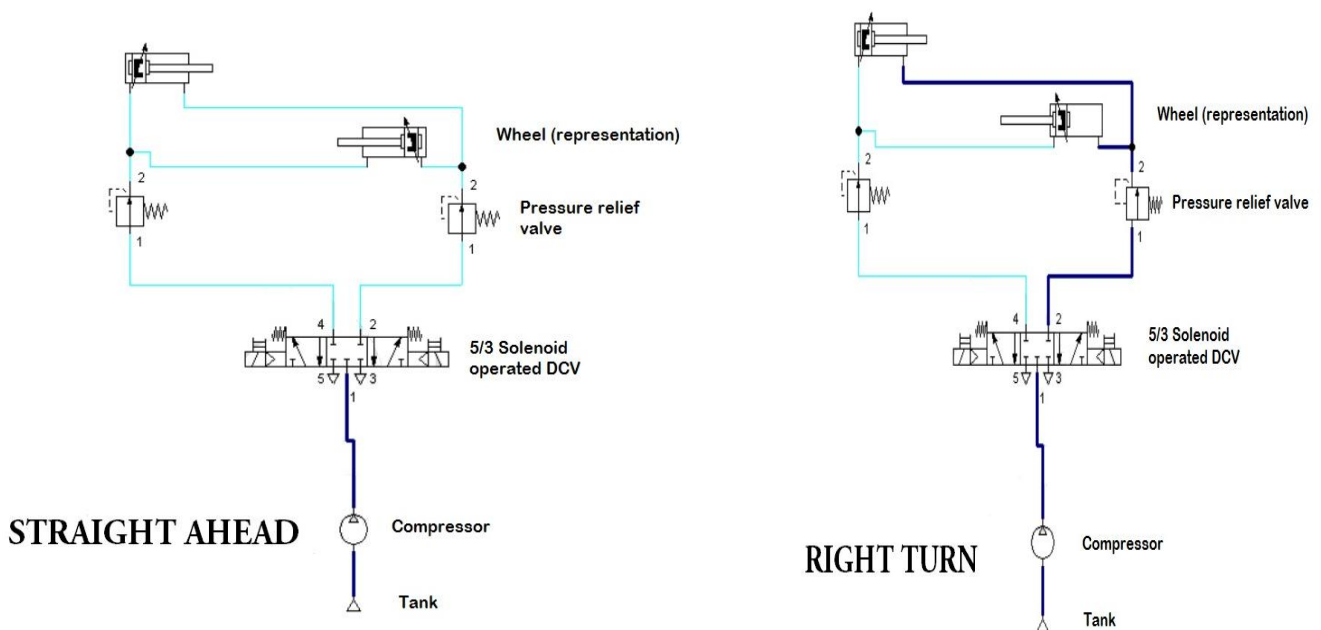


Figure 2: Circuit Diagram of system in straight ahead position

Figure 3: Circuit Diagram of system while taking right turn

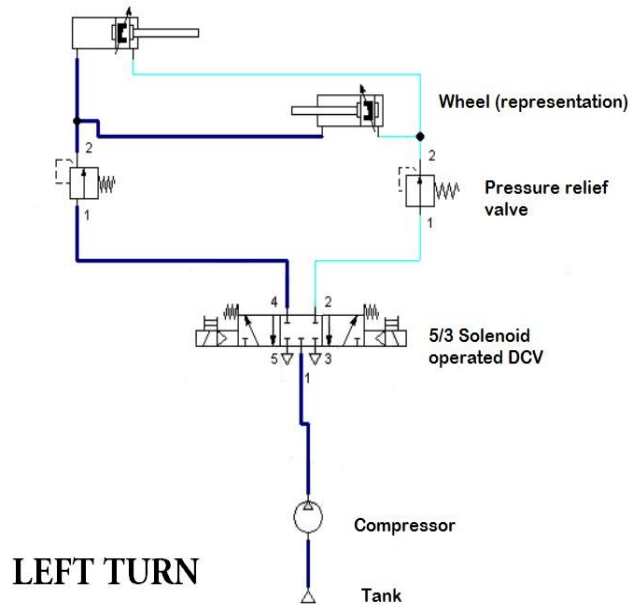


Figure 4: Circuit Diagram of system while taking left turn

#### TORQUE VECTORING UNIT:

Torque vectoring differentials are available in the market. Companies like ZF manufactures torque vectoring differentials. The system incorporates a brake based torque vectoring diffs. Output of the pneumatic is integrated to the differential. Impulses from controller actuate pneumatic and finally through differentials the desired action is achieved.

A torque vectoring differential similar to trivial one, except the additional braking setup or clutch, packed on the either side of the differential gears. During turns, speed to inner wheel is reduced and the outer wheel added, by braking or clutch mechanism.

#### V. CALCULATION AND MODES OF OPERATION

If the velocity of vehicle is known then the rpm of the wheels can be calculated by

$$V = 2\pi Nr / 60$$

Once the rpm is known on order to estimate the torque the over at wheel has to be determined.

$$P = RV / 3600\eta$$

Now, torque at wheel is

$$P = 2\pi NT / 60$$

But, torque at wheel is equal to that at inner and outer wheels, so

$$T_w = T_{wi} = T_{wo}$$

When a vectoring torque is deduced from inner and added to the outer wheel, the driving force at inner and outer wheel would be

$$D_i = (T_{wi} - T_v) / R_w \text{ and}$$

$$D_o = (T_{wo} + T_v) / R_w.$$

Thus the vectoring force would be  $D_o - D_i = 2T_v / R_w$

$M_z = T_v * W / R_w$  is the yaw moment due to the torque vectoring.

By the physics of cornering, the vectoring force induces a linear velocity that can in turn produce an angular velocity and make the vehicle about the inner wheel. B and C are the position of the front and rear inner wheels before turn and A is the position of the front inner wheel after the turn.

$F_v = mV^2 / B$  but,  $\omega = V / r \Rightarrow \omega = V / B$  and  $\theta = \omega * t$ , finally  $s = \theta * B$ , is the radial distance reduced.

## VI. RESULT AND CONCLUSION

MODE 1: (When the inner wheel angle is between 32 deg to 42 deg)

If,  $T_v = 300$  Nm, then force due to the  $T_v$  is,  $F_v = 556$  n

Yaw angle = 8.6  
Radial distance reduced = 600mm

MODE 2: (When the inner wheel angle is between 22 deg to 32 deg)

If,  $T_v = 150$  Nm, then force due to the  $T_v$  is,  $F_v = 278$  N

Yaw angle = 6.1  
Radial distance reduced = 402 mm

MODE 3: (When the inner wheel angle is between 10 deg to 22 deg)

If,  $T_v = 110$  Nm, then force due to the  $T_v$  is,  $F_v = 100$  N

Yaw angle = 4.5  
Radial distance reduced = 300 mm

Thus, the concept of torque vectoring based steering seems to promising in reducing the turning radius. Our work emphasizes that this system is effective and has high potential in heavy duty commercial vehicle and special vehicle application. Still a detailed research and study is needed to implement this.

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