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A Review of Rear Axle Steering System Technology for Commercial Vehicles

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Abstract: This study reviews the rear or tag axle steering system's concepts and technology applied to commercial vehicles. Most commercial vehicles are large in size with more than two axles. Maneuvering them around tight corners, narrow roads, and spaces is a difficult job if only the front axle is steerable. Furthermore, wear and tear in tires will increase as turn angle and number of axles are increased. This problem can be solved using rear axle steering technology that is being used in commercial vehicles nowadays. Rear axle steering system technology uses a cylinder mounted on one of rear axles called a steering cylinder. Cylinder control is the primary objective of the real axle steering system. There are two types of such steering mechanisms. One uses master and slave cylinder concept while the other concept is relatively new. It goes by the name of smart axle, self-steered axle, or smart steering axle driven independently from the front wheel steering. All these different types of steering mechanisms are discussed in this study with detailed description, advantages, disadvantages, and safety considerations.

Nomenclature

RAS : Rear Axle Steering
ECU: Electronic Control Unit
ETS: Electronic Trailer Steering
W_b : Wheel base
F_c : Centering Force, N
P_{Acc} : Accumulator Pressure, bars
Ps : Pump Pressure, bars
V : Speed of the vehicle, km/h

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1. Introduction

Large quantities of goods are transported from producers to consumers through the use of commercial vehicles. Commercial vehicles form the backbone of domestic logistics industry in countries that have a significant land mass, Korea being one of them. So, making small improvements in commercial vehicles can greatly impact the logistics industry.

Due to lack of desired maneuverability, many vehicles in warehouses need more space and are difficult to drive in tight spaces making it expensive to load or unload vehicles in warehouses. Further more, the accessibility of goods to hilly areas is hindered if the transport infrastructure is not fully advanced due to the absence of straight and wide roads. RAS systems comes in to help in such situations because it enhances the maneuverability of these vehicles using a hydraulic or electro-hydraulic system. Some RAS systems are installed on the rear axles without any hydraulic connection to the front axle while others need such connections. All of this depend on the design of the RAS system as discussed in this study.

Studies published by T. U. Kim et al. and T. J. Song et al. were about electric traction control of automobiles and predictive traction control algorithms for autonomous trucks but they did not use rear wheel steering.[1,2] If rear wheel steering is added to these vehicles the maneuverability will be positively affected and better traction control might be possible.

RAS systems have been studied by researchers at least for the past 3 decades. Studies done by Peng, B. et al., Guo, H. et al., Zhao L. et al., and Yamaguchi Y. et al., highlight the importance of control strategies involving or based on the rear wheel steering system used in electric vehicles.[3-6]. Apart from the studies done on electric vehicles, research work done by Deng B. et al., Shen H. et al., Ahmed M. et al. and Sedlacek T. et al. focus on controller development, minimum-time optimal control, and Hierarchical synchronization control strategy of Rear axle steering systems for other applications.[7-10] In 1989, mechanical and hydraulic steering systems were designed by Yilmaz and Mehmet for a rear axle of trailer having 3 axles.[11] For vehicles with higher number of axles, the rear axle steering systems become even more important. Wang Y. et al. considered a 9-axle vehicle and worked on the steering linkage optimization with active rear axle steering.[12] Rear axle steering system can be applied to multiple rear axles as is present in Demag AC 160-1 mobile cranes.[13] Other studies done by Pflug H.-C. et al., Momiyama F. et al. and Watanabe Y. et al. discuss the intelligent rear axle steering systems for commercial vehicles, gain/phase control of front and rear axles for trucks and buses and vehicle controllability and stability of a medium duty truck respectively.[14-16] In this study a review of different types of mechanisms, their pros and cons is done along with a description of how can the safety of the commercial vehicle be maintained when a rear axle steering is installed on a vehicle. There are commercial companies that provide these installation services. Many modern commercial vehicles have the RAS system already installed on them as a feature. However, if the mechanism is known and safety considerations are understood properly, as shown in this study, it is possible to design a rear axle system for any specific commercial vehicle.

RAS system provides maneuverability that is much needed in electric tractors. A study done by S. Y. Baek et al., focus on the control and maneuverability of agricultural all-wheel-drive electric tractors.[17]

The exact composition of a RAS system depends on the application. However, the most common parts include hydraulic cylinder installed on the axle, pump, safety mechanism and hydraulic valves. While designing any steering system, the wheels should turn by angles dictated by the Ackerman steering principle. Ackerman steering geometry was invented by Georg Lankensperger, a german wheelwright in 1816 in Munich.[18] The Ackerman steering principle is used by vehicles with 4 or more tires. For the tires to avoid slippage, the steering angle of each tire should follow the Ackerman principle. The same principle has to be followed by the RAS systems. Otherwise, there will be wear and tear in the tires with a tendency to slip. The

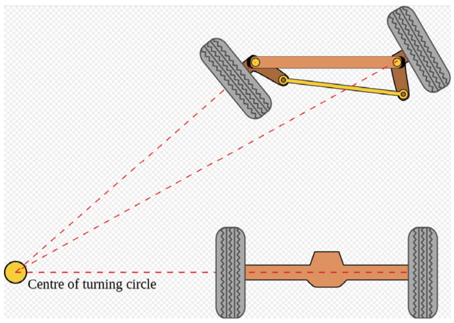

Fig. 1 Ackerman principle for 2 axle vehicle

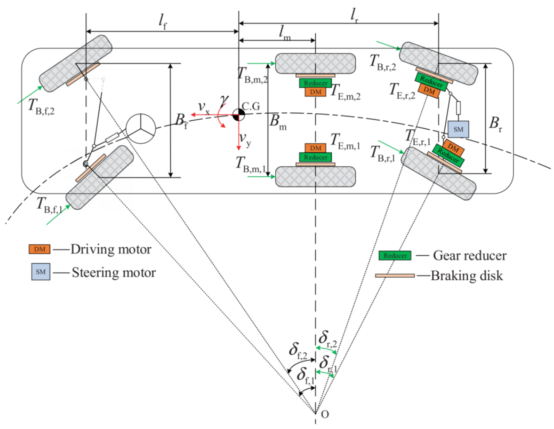

Fig. 2 Extended Ackerman Principle as used in Electric Bus by Wei Liu et al.[21]

principle is based on the fact that the wheels at the outer side of the curvature should be turned less as compared to those on the inner side. The geometry becomes more complicated when the no. of axles is increased. However, the basic principle remains the same i.e. tires should not slip when rotating in a curve.

Studies done by C.H. Park et al. and D. H. Hyun et al. involve the use of Ackerman steering in autonomous vehicle driving control and automatic steering system for parallel parking of a conventional vehicle.[19-20]

2. RAS System Design Types

2.1 Concept of Master-Slave Cylinders

RAS system designs that involve the concept of Master-slave cylinders and centering mechanisms were developed in the 1990s. One such example is shown in figure 3.[22]

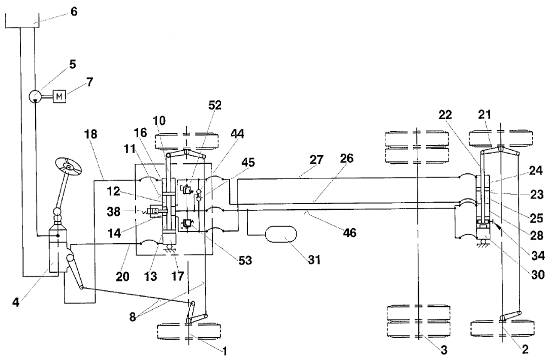

Fig. 3 A Patent by ZF Friedrichshafen AG.[22]

Fig. 3 shows one design of the rear axle steering system that was patented by a German company called ZF Friedrichshafen.[22] The main idea is to install a cylinder and centering mechanism on the rear axle. The steering cylinder on the rear axle is called slave cylinder and that on the front axle is called the master cylinder. The master cylinder and slave cylinder are connected through mechanical and hydraulic device. The displacement of master cylinder is controlled directly by the user however, the displacement of the slave cylinder is controlled by the master cylinder. At the same time a centering mechanism was suggested as shown in figure 4.

The centering mechanism uses an accumulator to center the slave cylinder whenever centering is necessary.

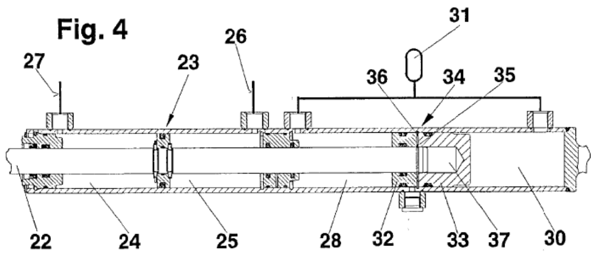

Fig. 4 Centering mechanism disposed on the Slave cylinder.[22]

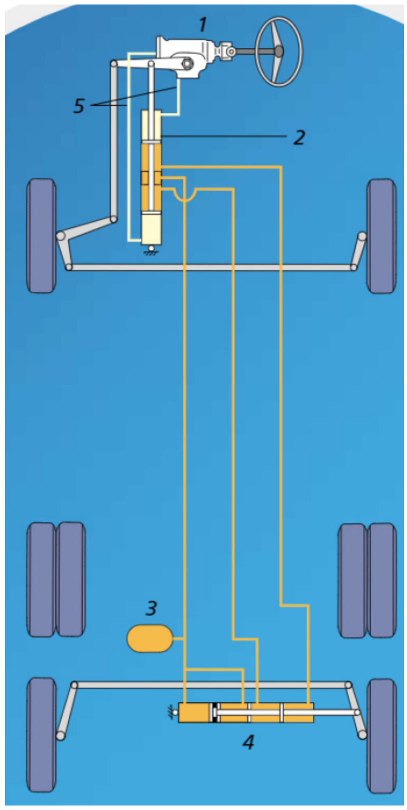

Fig. 5 ZF Servocom RAS.[23]

In such type of a design, the relationship between the master and slave cylinder is established through the use of a hydraulic component as shown in figure 3. That relationship is based on ackerman steering geometry as discussed earlier.

ZF servocom RAS is one of the products in the market as shown in figure 5. It is employed in commercial vehicles using the concept of master and slave cylinder.[23] In figure 5, part number 2 and number 4 serve as master cylinder and slave cylinder respectively. The slave cylinder is supplied with a centering mechanism that resembles the one explained in figure 4.

2.2 Smart Steering Design

Some companies like Bosche Mobility Solutions and VSE provide RAS system solutions specific to the user's vehicle. They provide the concept of smart steering or steer-by-wire solutions where all the calculations are done by the controller or ECU.[24-25)]

Smart steering is based on using the data from angle sensors, speed sensor, the diagnostic tests and the Ackerman principle all of which is fed into the ECU. The ECU then commands the valves that control the movement of the hydraulic cylinder so as the desired turning angle is reached.

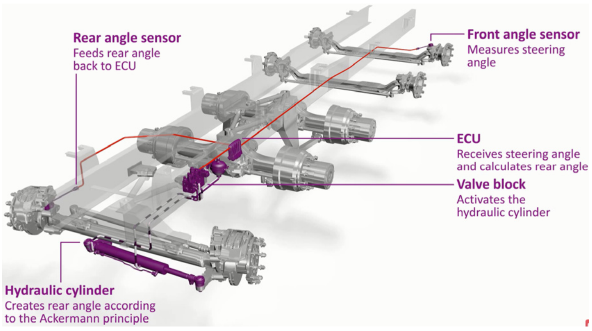

Fig. 6 VSE Truck Steering System.[26)]

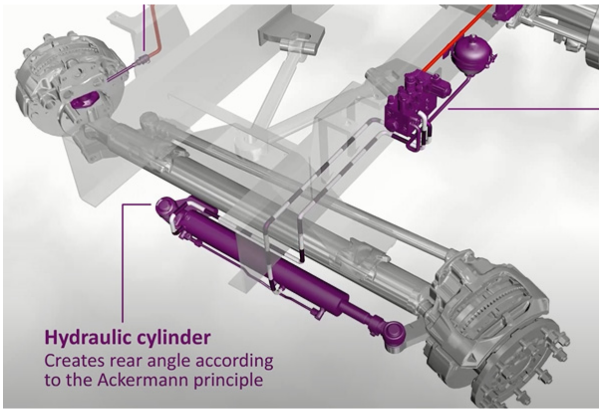

Fig. 7 RAS system in a position steered rightwards.[26)]

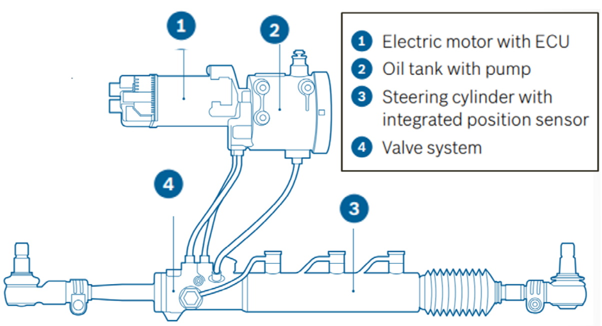

Fig. 8 Bosche Mobility Solutions RAS system.[25)]

Piston rod force	41/52 kN (retract/extend)
Max. pressure	185 bar
Installed length	1,000 mm +/– 95 mm
Operating temperature	–32 °C to +80 °C
Surface treatment	DIN EN ISO 9227 – 480 h
Operating voltage	24 V DC
Weight	24 kg

Fig. 9 Technical Characteristics of Bosche RAS system.[25)]

Bosche Mobility Solutions provide a Hydraulic cylinder for rear axle steering with standard specifications that is run with the help of 3 other parts as shown in figure 8.

This system is mountable as a standalone system with a 24kg weight. Other specifications of the system are given in figure 8.

As can be seen in figure 9, the operating voltage of 24V is required that requires connection to the battery of the vehicle. Furthermore, the weight has to be as small as possible to reduce any drawbacks because if the weight of the RAS system is increased too much the steering force would ultimately increase. The piston rod force of 41kN when retracted and 52kN when extended, means that the area is different on each side of the piston. It means that in this case, double acting cylinder with single rod is used in the RAS system. The length of retraction and extension is with in 0.95 m which would determine the linkage mechanisms and the platform geometry that is required for installing such system on the rear/tag axle of the vehicle.

3. Safety Considerations

3.1 Safety Issues with RAS system

If a vehicle with RAS system, while moving at high speed, is steered there is a possibility of the vehicle turning over due to the sharp turn caused by the increased steering. There are two ways of solving this problem as shown in previous studies. First method is to employ a centering mechanism and second method is to have an advance controller which will reverse the direction of the turning of the rear wheels at high speeds. The cylinder that is disposed on the rear axle for steering needs to have a way of shifting to a position in which the wheels would be straight and not steered. The reason for it is that if the vehicle is moving at a high speed and the RAS system starts to steer the rear axle there is a possibility of the vehicle turning over due to the sharp turn. So, any RAS mechanism needs to bring the cylinder to a centering position once the vehicle speed is more than or equal to a certain speed limit.

3.2 Centering Mechanism

The rear axle may be forced by a centering mechanism to come to the centering position whereby the wheels would turn to the straight ahead position. Once the vehicle speed reaches a certain limit, by activating the centering mechanism, the rear wheel steering is disengaged stopping the vehicle from turning over. One such centering mechanism is shown in figure 4. A more recent centering mechanism is shown in figure 10.

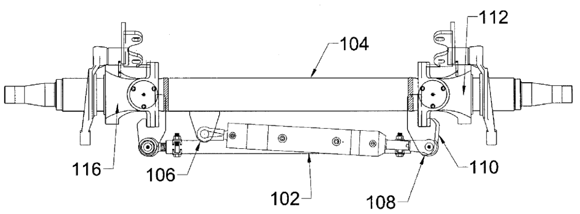

Fig. 10 A force steer axle assembly with redundant centering.[27]

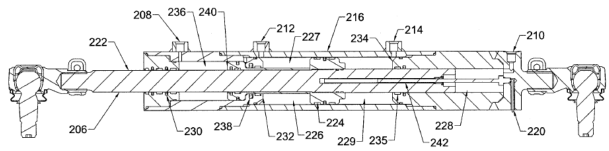

Fig. 11 Centering Cylinder Cross-sectional view.[27]

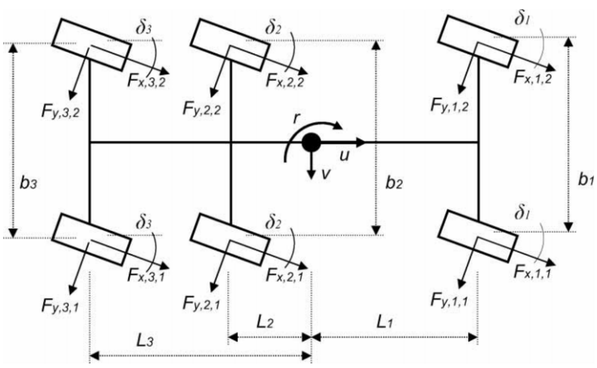

Fig. 12 Truck Chasis studied by Sogol K.[28]

In figure 11, the two centering pressure ports (208 and 210) are located at opposite ends of the cylinder (102). However, the mechanism in figure 4 has a centering ports on the right side of the cylinder. Both of these systems use accumulators for providing centering pressure.

3.3 Translational Movement Mechanism

If a vehicle is moving at a high speed and the driver steers the front axle. It will be dangerous if the rear wheels are turned in the opposite direction as is normally done at low speeds for increased maneuverability. However, if the rear wheels are steered in the same direction as the front wheels, the vehicle will translate without rotation and will shift its position while maintaining its direction. This concept was studied by Sogol K. et al. as shown in fig. 12.[28]

A difficulty in this type of mechanism is to achieve a high level of accuracy. Because of high vehicle speed, if the wheels are not tilted by the desired exact turning angle, the tires may be subjected to a high level of wear and tear exposing the vehicle to subsequent safety hazards.

3.4 Control Strategy for Safety Mechanism

It is important to know when the centering mechanism should be engaged or disengaged or when the rear wheels should turn in reverse direction as the front wheels. As stated earlier, the vehicle speed is sensed by a speed sensor which directly connected to the ECU or the controller. The controller then commands to engage or disengage the desired safety mechanism based on the data collected through the vehicle’s speed sensor and front angle sensor. Furthermore, redundancy is very important because if the rear axle safety mechanism is failed it may lead to an accident at higher speeds so some smart steering systems employ monitoring system that constantly monitors all the parts and if there is any failure, the system automatically goes to a centered position to avoid any accidents.

The angle sensors determine the current data of the vehicle steering condition and help the ECU decide whether to activate the steering of rear axle or not. Finding the right angle sensor or calibration of the

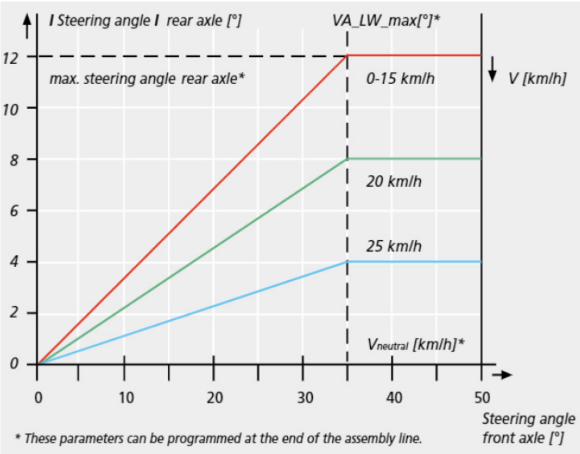

Fig. 13 ZF servocom RAS-EC Steering.[23)]

sensor is very important. There are certain studies that discuss the role of these angle sensors in commercial vehicles.[29)]

Figure 13 shows an example of how the ECU decides on the steering angle of the rear axle based on the front angle and the vehicle speed.

Fig. 14 Steering Cylinder with Centering Function by Weber Hydraulik.[30)]

TECHNICAL DATA	
HOLDING FORCE AT EXTERNAL PULL FORCE	84.1 kN
HOLDING FORCE AT EXTERNAL PUSH FORCE	80.8 kN
NOMINAL PRESSURE	210 bar
PISTON DIAMETER	80 mm and 70 mm
ROD DIAMETER	36 mm
CYLINDER STROKES	2 x 110 mm
OPERATING TEMPERATURE RANGE	-40 °C to + 80 °C
MATERIAL OF CRITICAL COMPONENTS	Steels with notched bar impact values KV min. 27 J. at -40 °C transverse/longitudinal
COATING AND CORROSION RESISTANCE	Nickel-chrome plating of the induction hardened piston rod with corrosion resistance 600h NSS R10' (optionally with bellows)

Fig. 15 Specifications of the cylinder shown in figure 13.

A company called weber hydraulik manufactures steering cylinder with centering function for mobile cranes RAS system.[30)] For safety purposes it has check valve and relief valves installed on the cylinder. Therefore, the safety against bursting of pipes is ensured. We can see the specifications of the centering mechanism in fig. 15. The system is robust which is an important safety factor.[30)]

From the figures above it is clear that the cylinder is to be connected to a nominal pressure source at 210 bars after which it can provide a centering force of 84.1kN in one direction and 80.8kN in the other direction. It means that a force of magnitude more than 84.1kN or 80.8kN would be required to perturb the cylinder once the centering mechanism is activated. So if the vehicle speed is more than a certain value it would become very difficult for the rear axle to steer, making the design safer but expensive. So, there should be a balance between the cost and the safety of the vehicle.

4. Conclusion

In the near future, the RAS steering systems will become an integral part of commercial vehicles because of the advanced maneuverability it offers. Depending on the axle weight rating, the specifications of the RAS system vary.

To allow a vehicle's rear axle steer, wheels should turn at angles that do not violate the Ackerman's principle. Otherwise, the RAS system will become devastating to the tires and safety of the vehicle.

The two most common techniques of RAS systems include the concept of master-slave cylinder, and a smart steering or steer-by-wire concept. In future, the focus will be on the smart steering or steer-by-wire because more and more vehicles are going to be electric and environmentally friendly. The advancement in batteries is yet another factor in its adoption in future vehicles.

RAS systems utilizes centering (more common) or translational mechanism to keep the vehicle safe when moving at high speeds. The RAS system should know when to engage or disengage the safety mechanism to keep the vehicle safe.

More recent RAS systems use more electronic parts than hydraulic parts. In future it can be expected that RAS system researchers will focus on the development of different types of angular sensors and control algorithms used in the ECU as compared to research on other components like hydraulic pumps, tank and cylinders.

Acknowledgement

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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