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Steering system design

The function of a steering system is to accurately guide the vehicle under all driving conditions. When the vehicle is steered, the driver's intentions are communicated using an intuitive rotational motion of the steering wheel. This motion is translated by the steering system into a wheel cut angle at the steered wheels. The steering system must be robust, sensitive and precise enough to inform the driver as comprehensively as possible about the various vehicle condition parameters and any changes in these parameters.

Extensive experiments have shown that information received by the driver's haptic receptors can be very finely distinguished, even by drivers with little experience. As a result it is very important that the angle of the steering wheel always corresponds directly to the orientation of the steered wheels and that only very minimal amounts of play are allowed in the force transfer system between the steering wheel and the vehicles wheels. It is also important that the driver continually receives information about the forces acting between the tires on the roadway. This information is transmitted to the driver by the torque acting on the steering wheel. To ensure that this information is effectively transmitted, connections between the force transfer elements within the steering system need to be as frictionless as possible.

Scientific investigations at the Centre for Transportation Science in Würzburg, Germany, has shown that the transfer of haptic information via the steering wheel is especially important when the vehicle is travelling at high speed, because the driver reacts considerably faster to haptic information than other types such as optical perceptions. This shows just how much a vehicle steering system influences the main chassis factors such as vehicle dynamics, safety and comfort. As a result of this influence the steering system greatly affects the overall character of the vehicle. The quality of the desired characteristics specified for a steering system together with wheel control, springing and damping, determine whether or not a driver feels safe and comfortable within a vehicle.

The driver's intention is transferred to the steering system by the rotation of the steering wheel. This is then transmitted through the steering shaft, steering gear, tie rods, and steering arms to the wheels. This must take place distinctly, reliably, simply, accurately and under all possible operating conditions. This is specified by regulation (e.g. European directive 70/311/EWG, StVZO SS38). The goal of such directives is to ensure that every vehicle exhibits behaviour that can be estimated and predicted by the driver. In addition to general requirements regulations contain maximum values for the largest allowable actuation force and the time length of actuation for both steering systems that are operating correctly and in the event of a malfunction.

In recent automotive history, the main passenger vehicle steering designs have proven successful in fulfilling the necessary requirements. Due to their low required actuation forces, circulating ball steering systems are most appropriate for use in larger passenger vehicles with manual steering, while rack and pinion steering has long been the most commonly used solution for smaller vehicles.

Increasing expectations for comfort caused mechanical steering systems to be replaced by hydraulic power steering systems in the 1980s. This led to the dominance of hydraulic rack and pinion steering in all passenger vehicle markets worldwide. Hydraulic recirculating ball steering systems still dominate the commercial vehicle market today, but are only occasionally found in SUVs and pickup trucks. The higher system costs associated with this type of steering system negatively impact vehicle manufacturing costs but its extreme robustness allows for more heavy duty applications and its packaging flexibility enables increased ground clearance.

Two different versions of hydraulic rack and pinion systems have developed, both based on the same simple fundamental principle. For vehicles with a steering rack vertically located near the bottom of the vehicle, the steering rack can be longitudinally located either in front of or behind the front axle centreline. The tie rods on the steering systems are connected directly to the ends of the rack. The pinion can be located either above or below the rack. This type is usually referred to as a lateral drive hydraulic rack and pinion steering system.

As front-wheel drive, usually in combination with a laterally mounted front engine and a MacPherson type front suspension, became more popular on vehicles below the mid-size level, a bottom mount rack and pinion steering system with laterally connected tie rods was not initially possible because of the packaging restrictions. Therefore it became common to shift...
the steering system upwards to a location near the firewall. In order to reach the steering arms from this position while maintaining acceptable tie rod angles, the tie rod joints were radially mounted to the centre of the rack. This resulted in a hydraulic rack and pinion steering system with centrally connected tie rods, also known as a central drive hydraulic rack and pinion steering system.

This type of steering system involves a considerably more complex design and is more technically sophisticated, heavier and more expensive than one with an axially connected rack. Special designs were created in order to eliminate some of these disadvantages, for example those used on a previous series of Audi 80 and VW Passat. This design features an asymmetrical cylinder integrated near the opinion and cantilevered rack ends. Although notable quantities were produced for mid-size vehicles in the 1980s and 1990s, this design is rarely used today.

Owing to the advantages discussed above, the lateral drive hydraulic rack and pinion steering system has long since proved to be the most successful design.

Steering driveline components

The steering driveline connects the steering wheel to the steering gear by means of the mechanically interlocking components required by current regulation. This includes the steering shafts, universal joints, and elastic coupling, as well as telescoping and collapsible elements. These components connected together enable precise and loss free transfer of steering angles and torques from the steering wheel to the steering gear.

Universal joints are used to allow the steering driveline to contain multiple angles. However, when rotating, an angled universal joint generates uneven irregularities in torque transmission, and multiple connected universal joints are orientated, so that these irregularities compensate for one another minimising or eliminating errors.

If a steering driveline contains unacceptable residual errors (e.g. all-wheel drive vehicles or left-hand and right-hand drive alternatives) constant velocity double universal joints with a centering function are needed. In order to prevent unpleasant oscillations and noise (NVH) generated by the suspension and steering system from reaching the steering wheel, the steering driveline contains an elastic coupling.

Telescoping systems enable the steering wheel to be adjusted axially, whereas telescoping/collapsible systems also allow the steering driveline to collapse for driver safety during the crash (Figure 5).

The upper portion of the steering column is mounted on ballbearings and contained within a jacket tube to enable the adjustment of the steering wheel. The jacket tube contains the steering column locking mechanism and passenger safety devices that are configured to absorb energy during the crash. Additionally the control unit and the interior trim panels are mounted to the jacket tube.