

Applications – Chassis & Suspension – Steering system

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4 Steering system

4.1 Introduction

The steering system is the key interface between the driver and the vehicle. The main requirement is that the steering should be precise, with no play. In addition, the steering system should be smooth, compact and light. It must also provide the driver with a perfect feel for the road surface and help the wheels return to the straight-ahead position.

The standard steering arrangement is to turn the front wheels using a hand-operated steering wheel via the steering column. The steering column may contain several joints to allow it to deviate somewhat from a straight line. These joints may also be part of the collapsible steering column design to protect the driver in frontal crash situations.

4.1.1 Operating mechanisms

There are two basic steering mechanisms:

- Rack and pinion steering
- Recirculating ball steering.

Most modern cars use the rack and pinion steering mechanism. The recirculating ball mechanism has the advantage of a much greater torque multiplication, thus it was originally used on larger, heavier vehicles while the rack and pinion was limited to smaller and lighter cars. But with the almost universal adoption of power steering, this is no longer an important advantage, leading to the increasing use of the rack and pinion mechanism on new cars. However, power-assisted recirculating ball steering systems are still applied today in dynamic sports cars, upper class cars, off-road vehicles and vans. Despite the ability to safely transmit high torques, the recirculating ball system is characterized by low system friction, high efficiency and good noise performance.

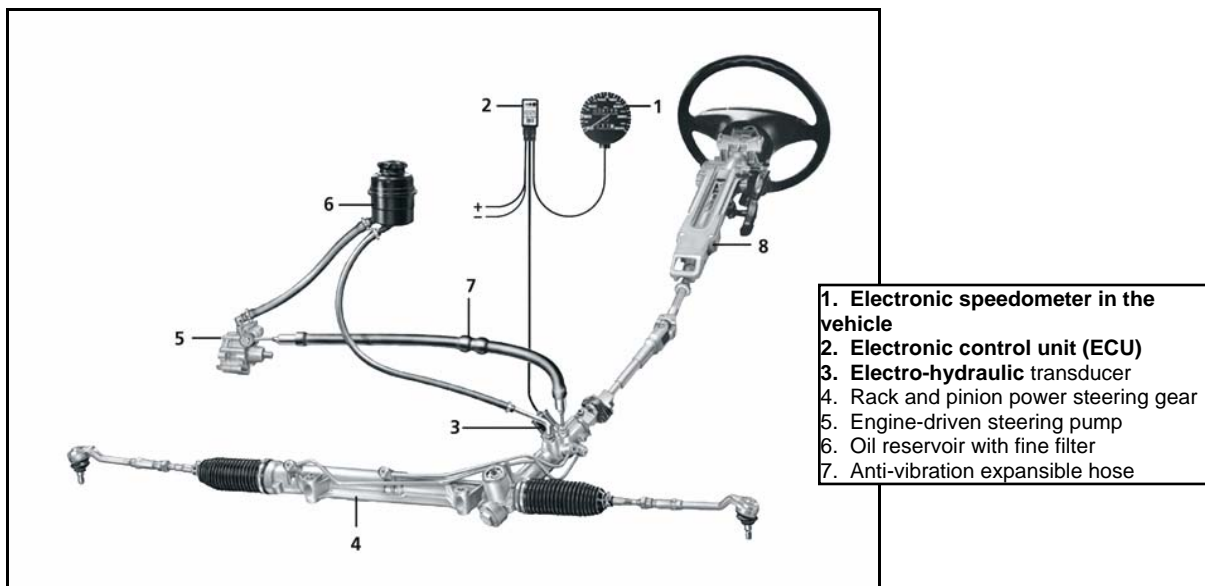
In the rack and pinion system, a pinion gear is attached to the steering shaft, i.e. turning the steering wheel turns the pinion gear which then moves the rack. The rack and pinion gear is enclosed in a metal tube, with each end of the rack protruding from the tube. It does two things:

- ⚡ 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.

A tie rod at each end of the rack connects via the swivel ball joint to the steering arm which finally moves the wheel. The specific advantage of the rack and pinion design is a good feedback and a direct steering "feel".

In a recirculating ball steering box, a box is clamped over a worm drive that contains dozens of ball bearings. The ball bearings loop around the worm drive and then out into a recirculating channel where they are fed back into the worm drive again. As the steering wheel is turned, the worm drive turns and forces the ball bearings to press against the channel inside the nut. This forces the nut to move along the worm drive. The nut itself has a couple of gear teeth cast into the outside of it and these mesh with the teeth on a sector gear which is attached to the cross shaft.

4.1.2 Power steering systems

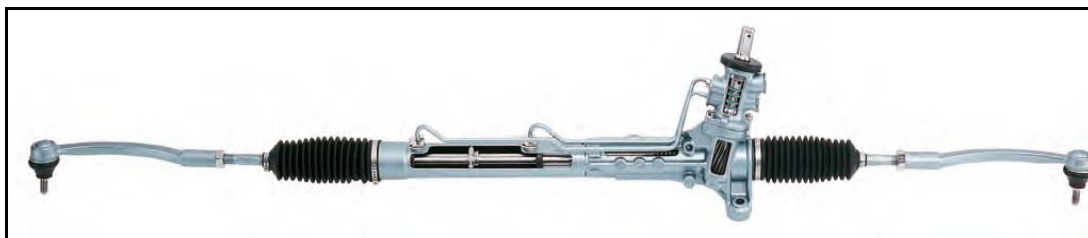


Configuration of a modern hydraulic steering system (Photo: ZF Lenksysteme)

As vehicles have become heavier and switched to front wheel drive, along with an increase in tire width and diameter, the effort needed to manually turn the steering wheel has increased. Therefore power steering (or rather power-assisted steering) was introduced to assist the driver. A specific advantage of power steering is speed adjustable steering, where the steering is heavily assisted at low speed and lightly assisted at high speed. This feature is gradually becoming commonplace across all new vehicles.

There are two types of power steering systems - hydraulic and electric/electronic. Also hydraulic-electric hybrid systems are possible.

The dominating steering solution for today's vehicles is rack and pinion hydraulic steering. In a hydraulic power steering system, a part of the rack contains a cylinder with a piston in the middle. The piston is connected to the rack. Supplying a higher pressure fluid to one side of the piston forces the piston to move, which in turn moves the rack. The hydraulic power steering system uses hydraulic pressure supplied by an engine-driven pump to assist the turning motion of the steering wheel. This system offers good value and functionality, a high level of reliability, and has a proven safety record. Major components, aside from the rack and pinion, include the pump providing the hydraulic pressure, the valve assembly, the rack tube housing as well as flexible bellows and pressure lines.



Hydraulic power steering system

Source: ZF Lenksysteme)

Hydraulic-electric hybrid systems allow a conventional hydraulic steering system to run without an engine-driven hydraulic pump. The hydraulic pressure is supplied instead by an electric motor pump unit independent of the engine. This concept is particularly useful in vehicle platforms that utilize conventional hydraulic steering as a base technology, but are also offered for hybrid electric vehicle variants.



Electrically powered hydraulic steering system

Source: TRW Automotive

Nowadays, however, electrically assisted power steering is gaining more and more market share. Electric power steering works by using an electronically controlled electric motor which replaces the conventional hydraulic system. It is superior to conventional hydraulic power steering in many respects. The ride characteristics of the car are considerably enhanced because the electrical control perfectly responds to vehicle dynamics and handling. It is also more efficient than the hydraulic power steering, since the electric power steering motor only provides assistance when the steering wheel is turned, whereas the hydraulic pump runs constantly. Thus the introduction of electric power steering allows a fuel saving of 3 – 4 %.

In electrically assisted steering, the assist level is easily tunable to the vehicle type, road speed, and even driver preference. An additional benefit is the elimination of potential environmental hazards posed by leakage and disposal of hydraulic power steering fluid. Also in the event of the engine cutting out, steering assist will not be lost - whereas hydraulic will stop working, making the steering doubly heavy as the driver has to turn the power-assist mechanism on top of the steering system itself. Furthermore, apart from the servo unit, there are no additional components: steering valve, steering pump, oil reservoir and high-pressure hoses are unnecessary. This saves weight and facilitates installation in the vehicle. Finally, electronically controlled electric steering systems also work in tandem with other driver assistance systems and thus make an active safety contribution.

Depending on the vehicle class, there are three basic types of electric power steering systems. The servo unit is either mounted:

- ▲ on the steering column,
- ▲ on a second pinion
- ▲ or in parallel to the steering rack,

depending on the available installation space, the vehicle power supply and the required steering rack force.

For small to medium cars, where the steering efforts are relatively low, the servo unit and its electronic control unit are integrated in the steering column. They are connected to the mechanical rack and pinion steering gear via the intermediate shaft with universal joints. The torque produced by the electric motor is converted, via a worm gear, into an assistance torque and transmitted to the intermediate shaft. The result is an extremely lightweight design that requires very little space. The location of the servo unit and the electronic control unit in the passenger compartment saves space in the closely packed engine compartment and enables reduced temperature as well as sealing requirements compared with systems situated under the hood.



Electric power steering system with the servo unit on the steering column

Source: ZF Lenksysteme

Electric power steering systems with the servo unit on a second pinion are designed for mid-size or upper midsize cars. The assist power is applied directly to the rack. This design allows for lower inertia, lower friction and more direct steering feel, as well as superior response. The physical separation of the sensor and the drive unit offers the opportunity for a performance-optimized configuration and improved crash safety thanks to optimum use of the available installation space.



Electric power steering system with the servo unit on a second pinion

Source: ZF Lenksysteme

Electric power steering systems with paraxial drive are designed for high performance applications. They are characterized by low system friction and high efficiency. Due to the combination of recirculating ball gear and toothed belt drive, systems with paraxial drive are ideally suited for differing high performance requirements. The wide range of positioning possibilities of the servo unit allows optimum use of the installation space on the vehicle and helps to meet the highly demanding crash safety requirements of the automotive industry.



Electric power steering system with paraxial drive (Photo: ZF Lenksysteme)

In the past fifty years, car steering systems haven't changed much. But there will be significant advances in car steering in the next decades. Of particular interest is the introduction of "steer-by-wire" or "drive-by-wire" systems. Such systems completely eliminate the mechanical connection between the steering wheel and the steering mechanism at the wheel, replacing it with a purely electronic control system. The steering wheel will essentially only contain sensors that tell the car what the driver is doing, whereas some motors in the steering wheel will provide the driver with feedback on what the car is doing. The output of the sensors will be used to control a motorized steering system. "Steer-by-wire" will reduce the vehicle weight, free up space in the engine compartment by eliminating the steering shaft and also reduce vibration inside the car.

4.2 Aluminium components of the steering system

Safety and driving comfort are the characteristic requirements for the mechanical components of the steering system. Materials selection and product design are determined by the requirements regarding inertia forces, vibration damping, strength and crashworthiness of the components.

The steering system has all along been an area for the application of different aluminium alloys and manufacturing technologies, including both cast as well as wrought alloy components. In particular, the aluminium steering column has been the domain of innovative technologies such as impact extrusion (followed by secondary forming operations) or rotary swaging of aluminium tubes. Aluminium components within the steering system offer excellent examples for the potential of massive forming methods for the production of safety-critical lightweight components.

4.2.1 Steering wheel

Steering wheels for passenger cars are generally circular, and mounted to the steering column by a hub connected to the outer ring by one or more spokes. The steering wheel is also the usual location for a button to activate the horn. In addition, the driver airbag is integrated into the steering wheel. Furthermore, electronics capabilities are becoming increasingly important. Thus more and more electronic buttons and features are integrated within the steering wheel. Newer developments include fixed hub steering wheels that offer major advantages to the traditional steering wheel. Because the hub is fixed, it can contain an asymmetric airbag to give the driver improved protection. It can also hold a large number of controls which are more visible and easily accessible to the driver.

Steering wheels are generally manufactured as a single unit. Aluminium (or magnesium) die castings are normally used for the frame. The die cast frame is then over-molded with flexible polyurethane foam. Additional production processes include leather and wood processes, one shot and two shot plastic injection (for plastic parts like airbag covers) and electronic component assembly.

But metallic steering wheel frames are today strongly challenged by high performance plastics, e.g. glass-filled polycarbonate-siloxane copolymer resins. Reported benefits of high performance plastics claim up to 20% system cost reduction and a 40% reduction in mass compared to a magnesium or aluminium alloy steering wheel.

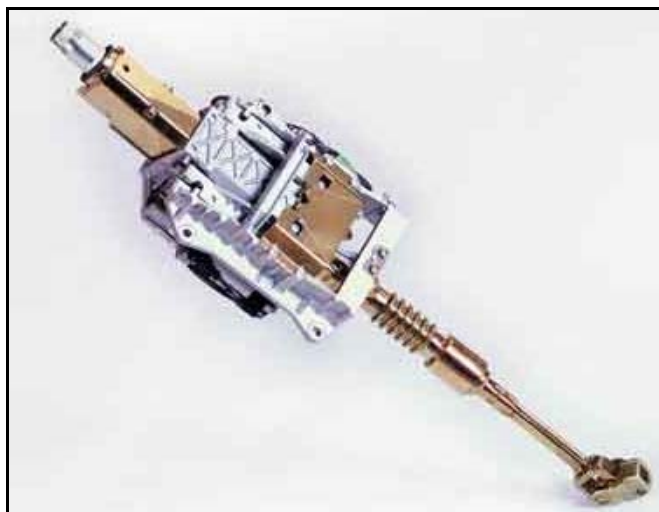
4.2.2 Steering column

Steering columns are usually standardized assemblies that can be installed in a variety of vehicles. Their main function is:

- ⤴ to flawlessly transform steering movements through the lifetime of the car, and
- ⤴ to protect at any time the driver in case of an accident.

In terms of design, the steering column has to be light and stable, but also readily collapsible to minimize the risk of injury in the event of a crash.

Nowadays, fixed, non-adjustable steering columns are found relatively seldom. The ability to adjust the steering wheel for height and reach is today a standard comfort requirement of the driver. Therefore fixed steering columns have been largely replaced by electrically or mechanically adjustable steering columns.



Fixed, non-adjustable steering column (above) and steering column which is electrically adjustable for height and/or reach (below)

Source: ThyssenKrupp Presta

Adjustable steering columns require a relatively complex console. The parts of the console which serve as a sled for the steering shaft are often designed as aluminium high pressure die castings. The application of the aluminium high pressure die casting technology ensures a low weight, high stability and good collapsibility, factors that reduce the overall weight of the

vehicle and maximize passive safety. But it also offers a cost-effective solution for the production of the intricately shaped component.



Manually adjustable steering column with a continuously variable clamping mechanism (above) and an electric variant (below) with memory function

Source: ZF Lenksysteme)

Traditionally, the steering shaft, i.e. the inner shaft of the steering column which conveys the torsional moment, has been produced from thin-walled steel tubes. However, today, lightweight solutions made from wrought aluminium alloys are more and more used too. The individual parts of the steering shaft are characterized by relatively complex geometries due to the different joints and other features necessary because of the different functional requirements, the geometrical boundary conditions and the safety considerations.



Steering shaft elements are produced in different variants including for example also vibration damping elements

Source: ThyssenKrupp Presta

A specific manufacturing option for steering columns is cold rotary swaging of aluminium tubes. Rotary swaging is a technology highly suitable to produce the characteristic elements of steering shafts such as closely controlled variations of the outer diameter or the introduction of internal gears.

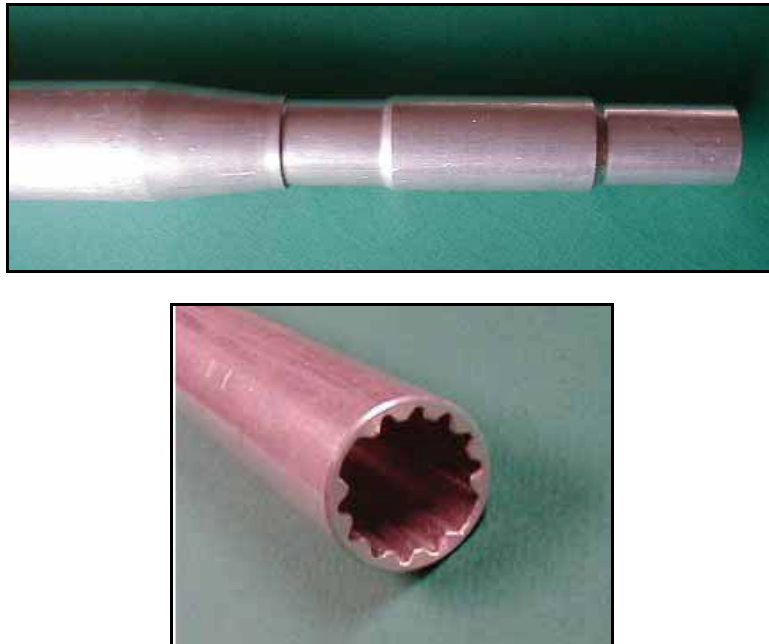


Figure 1: Characteristic elements formed by rotary swaging of aluminium tubes

Source: HMP



Figure 2: Steering column element produced by rotary swaging

Source: HMP

Impact extrusion is another forming process that is particularly suitable for the fabrication of near-net-shape or net-shape cylindrical parts. In general, the cold impact extrusion technology is applied to form complex aluminium shapes with close dimensional tolerances, although, in particular for larger parts, also warm impact extrusion is possible. As impact extrusions leaves the fibre orientation undisturbed and results in a non-porous microstructure, it is a manufacturing method ideally suited for the production of safety-critical components. The geometrical shape of typically impact extruded components has generally a rotational symmetry. But to a certain extent, also attachment geometries like yokes, etc., are possible.

Through successive cold processing steps, also convolutions and splined sections can be realized.

Figure 3 shows some steering shaft components, figure 4 an example of a one-piece aluminium tube with convolutions, compared to a four-piece assembly in steel. The convolutions help the tube to meet the requirements on compressible forces and to bend, but the part will still keep its integrity in a crash situation.



In order to avoid tensile stresses when forming such complex extremities by cold impact extrusion, the material must be put under high compression forces. High capacity presses are necessary to keep the work pieces under pressure. The extreme forces also ask for the development of special tool designs, which can withstand the high impact forces in large series production.

The alloy EN-AW 6082 is mainly used for its good overall performance. The alloys EN-AW 7108 and EN-AW 7021 are used where high strength is required, i.e. in steering shafts. The products are used in the engine compartment without surface protection.

Figure 5 shows some other steering shaft components of various geometries, of particular interest are the inner splines and the fork legs. The specific benefit of impact extruding is the excellent grain-flow combined with the smallest possible overall dimensions.

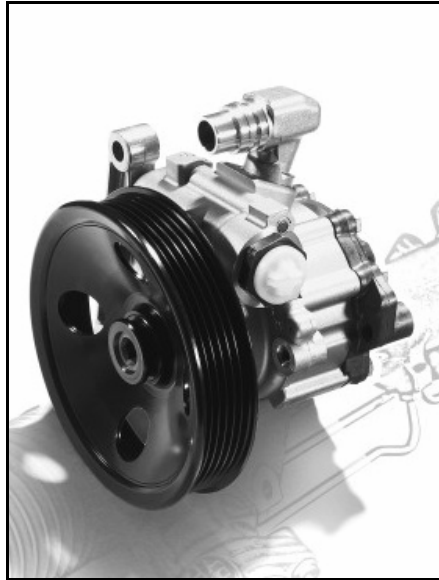


Impact extruded steering shaft components of different geometry

Also a range of linkage products, including the control rod of the steering gear, the track rod ends, the control arms, etc., are possible aluminium components.

4.2.3 Components of the power steering system

Further aluminium applications can be found in power-assisted steering systems. In hydraulic power steering systems, the hydraulic components such as the **steering pump** and the **hydraulic tubes** are preferred aluminium applications offering an excellent balance between minimum weight and maximum performance.



Steering pump for hydraulic power steering system

Source: ZF Lenksysteme

The electric power steering system requires an electric drive consisting of motor and control unit. These components can be integrated into a module ("PowerPack") which needs little installation space and has a high power density. The housing shown below made from an aluminium extrusion with a specifically designed cross section is an excellent example for an optimized lightweight solution.



PowerPack for an electric power steering system

Source: ZF Lenksysteme

Further aluminium parts are found in the rack and pinion power steering gear, where aluminium high pressure die castings provide cost-effective possibilities.



Rack and pinion power steering gear, an aluminium die casting

Source: ZF Lenksysteme