ZF Rack and Pinion Power Steering Gears
for Passenger Cars and Light Commercial Vehicles
Millions of vehicles. We can do the steering.

As vital for the vehicle as the engine and the wheels, as important for safety as the brake – the steering system is at the heart of every vehicle. Whether it be a question of operation, safety or ride comfort, one thing is clear – the overall quality of the vehicle also depends on the quality of the steering. The requirements are clearly defined – the steering must be precise and free from play, easy to operate and direct, compact and light in weight. Moreover, it should give the driver a good “feel” of the road and favor the return of the steered wheels into the straight-ahead position. It has to work shock-free, should require as little maintenance as possible and, at the same time, offer a maximum of safety and comfort at both high and low speeds.

When it comes to safety potential, the power steering gear really comes into its own at high speeds. Abrupt steering corrections – when maneuvering to avoid an obstacle, for example – are easy to master thanks to the power assistance provided by the servo mechanism. Also, the hydraulic system will compensate for the most part for sudden, one-sided steering forces. The driver is able to react to the surprise, keep the vehicle on track and bring it to a halt. And all this only requires a little extra effort on the steering wheel.
ZF Lenksysteme. Steering toward the future.

As a joint venture of Robert Bosch GmbH and ZF Friedrichshafen AG, ZF Lenksysteme GmbH has produced power steering systems for passenger cars and commercial vehicles for several decades. The products fulfill every specified requirement. Take rack and pinion and recirculating ball power steering gears, for example. These tried-and-tested steering designs have been continually further developed, protected by numerous patents, and adapted to suit specific vehicle requirements. The development of the ZF compact power steering gear involved the forging of new paths both in valve design and in production processes.

One product of this approach that really stands out is the ZF Servotronic, an electronically controlled and speed-sensitive rack and pinion power steering gear for passenger cars and light commercial vehicles. It is characterized by easy, comfortable steering in parking operations and a feeling of safe driving at increasing speed as a result of more stiffness at the steering wheel.

The ZF Active Steering sets new standards for implementing both kinematic steering assistance functions and driving stabilizing functions. It allows driver-independent steering interventions without the need to separate the mechanical connection between steering wheel and front axle. The variable steering ratio coupled with this clearly increases driving comfort at low speeds.

Servotronic® is a registered trademark of ZF Lenksysteme GmbH.

Installation schematic for a ZF compact power steering gear with steering column, engine-driven steering pump and oil reservoir as well as pressure, suction and return lines.
Mechanical construction

The ZF rack and pinion power steering gear basically comprises a mechanical steering gear, the steering valve and an integrated power cylinder.

The rack (2) with the integrated piston (3) is guided in wear-free plain bearings within the power cylinder of the housing (1). The pinion (4), which runs in bearings in the valve area, meshes with the rack teeth. The rack is pressed against the pinion by means of a spring-loaded yoke so that the teeth always mesh without play. The pinion is connected with the valve rotor (5) through a torsion bar (6). The rotary motion of the steering wheel is transformed by the pinion into an axial motion of the rack and transferred to the steering arms by tie rods (8).

The ZF rotary valve is a valve design that has proved itself time and time again in millions of applications. It is used in order to control the pressurized oil needed for power assistance. This valve design mainly comprises the valve rotor (5), which has six control grooves on its surface area, and the valve sleeve (7) securely connected with the pinion (4).
The valve bore of the valve sleeve has axial grooves that are matched to the control grooves of the valve rotor. The centering of the valve rotor (neutral position) is by means of a conventional or a positive center feel torsion bar (6) which is also the connecting element between the valve rotor, the pinion and the valve sleeve. The valve rotor and pinion run in anti-friction bearings to ensure the precision of operation and the functional safety of the steering valve even at high pressures.

If a torque coming from the steering wheel or from the steered road wheels is transmitted to the valve rotor or to the securely connected pinion and valve sleeve, respectively, a relative rotary motion influenced by the torsion bar will occur between the valve rotor and the valve sleeve. The valve rotor is thereby caused to change its position in relation to the valve sleeve bore surrounding it, so that the relative positions of the control grooves are changed, too. Pressurized oil can now flow through pipes to one of the two power cylinder chambers (ZL or ZR) and assists the axial movement of the rack if the turning motion is initiated from the steering wheel. If, however, the axial movement of the rack is caused by the road wheels, the steering valve will, in spite of the steering wheel being held, direct the pressurized oil to that power cylinder chamber which counteracts rack axial movement. This braking effect dampens road shocks. When the steering wheel is released, the action of the twisted torsion bar makes the control grooves return to the neutral position, and the same system pressure will exist in both of the power cylinder chambers.
Basic hydraulic function of the ZF rotary valve

The hydraulic fluid delivered by the steering pump (19) flows through a connecting bore in the valve area, via the feed oil radial groove (9) and transverse bores in the valve sleeve (7), onward to the three feed oil control grooves (10) of the valve rotor. In the valve neutral position (fig. see page 4/5) the oil flows, over the open feed oil control edges (11), to all valve sleeve axial grooves (12) and from there, over the open return oil control edges (14), also to the return oil control grooves (13) of the valve rotor. From these grooves the oil flows back, via connecting bores, to the return oil chamber (15) and from there to the oil reservoir (20). At the same time, the radial grooves (16 and 17) of the valve body and their associated pipes provide for a connection between the right-hand (ZR) and left-hand (ZL) power cylinder chambers. When turning the steering wheel clockwise (top fig.), the rack with the integrated piston will move to the right in the piston bore (to the left in the installed position on the vehicle) if the pinion is situated on top. Due to the simultaneous rotation of the valve rotor to the right, the pressurized oil is directed, over the further opened feed oil control edges (11), to the three associated axial grooves (12), via bores to the radial groove (17), and, via a pipe, to the
Special equipment

The ZF rack and pinion power steering gear can be fitted with a number of equipment options in order to adapt it in an optimum way to the kinematic and motorization conditions existing on the vehicle.

Variable ratio

Besides the constant ratio version, the rack and pinion power steering gear can also be made available with a variable ratio. The rack teeth have varying modules and pressure angles so that, on the one hand, one can ensure that, around center (i.e. in straight-ahead driving), the steering offers the response the driver is accustomed to. On the other hand, as the steering wheel turning angles (to the right and to the left) become greater, the ratio becomes lower and the steering in consequence becomes more direct. The difference between the lowest and the highest ratio can be as much as 35%. As a result, values as unusually low as approx. 2 steering wheel turns from lock to lock can be achieved.
Positive center feel torsion bar
The torsion bar is a most important component in the steering valve. Its design is decisive for steering accuracy and steering feel at different driving speeds. When the steering valve is actuated, in other words, when steering wheel motion begins, the torsional force of the torsion bar must be overcome. Without this resistance the steering valve would be too light and, in consequence, could not be actuated in a precise and controlled manner. In order to optimize the steering valve in the initial-hydraulic-assistance range and, thereby, the steering characteristics, in particular at higher speeds, ZF Lenksysteme GmbH has developed the positive center feel (PCF) torsion bar on the basis of the conventional torsion bar (top figure). Besides the conventional rotary valves and rotary spool valves, this PCF torsion bar is used with the ZF Servotronic steering valves.

The main elements of this compact component are: a torsion bar, a preloaded, torsion-proof metal bellows spring, two sleeve-shaped end pieces and a prism centering device provided with balls. The torsion bar is positively connected with the two end pieces. The metal bellows spring, which is arranged coaxially with the torsion bar, is fastened to one of the end pieces at one end and to a centering piece at the other end.

The prism centering device consists of two centering pieces each of which is provided with a prism-shaped recess at its front end. Cage-guided balls are arranged between these recesses. The zero-torsion position of the axially preloaded metal bellows spring is determined by the prism centering device.

Right at the beginning of the torsional motion, the metal bellows spring produces a substantial additional torsional resistance. As soon as the prisms of the two centering pieces are displaced to one another (starting from a torsion angle of approx. 0.2°), the high metal bellows stiffness is no longer present, and torsional rigidity takes a shape similar to the characteristic of the standard torsion bar.
Nominal characteristic curve
This is a curve characteristic that covers a very narrow tolerance band. Conically formed control grooves and control edges on the valve rotor and the valve sleeve, coupled with controlled assembly technique, allow optimum configuration of the valve characteristic curve in line with vehicle manufacturer specifications.

Hydraulic steering limiter
There are functional, economical and environmental advantages in integrating a hydraulic steering limiter into rack and pinion power steering gears. A chassis with sufficient self-aligning properties is, however, a prerequisite for this.

Specially developed connecting cross sections in the cylinder bore enable an overflowing of the oil from the cylinder chamber under high pressure to the return oil chamber separated from it by the piston, just before the end of the stroke. The pressure drop at the lock stop resulting from this protects the steering pump and the mechanical parts of the steering gear from excessive loads. A power assistance heavily reduced by the pressure drop causes an increase of the steering wheel input torque and, thus, informs the vehicle driver that maximum wheel lock is imminent.

As the hydraulic steering limiter reduces the power requirement of the steering pump, the engine idling speed can be set at a lower value, thus saving a considerable amount of fuel which, in turn, protects the environment.

Steering damping
The main reason for increased levels of steering comfort is the fact that shocks caused by the road and the chassis cannot be felt on the steering wheel. In particular cases, additional technical solutions can be adopted, such as fixing the steering gear by rubber mounts. But it is also possible to use valve and orifice systems (variable orifices) which are integrated into the hydraulic system and act as dampers.

Full-lock damping
If required, ZF rack and pinion power steering gears can be fitted with flexible plastic components on the stroke limiters. The damping effect in front of the metallic stop (full lock) combats unwanted noise at maximum wheel lock.
Mechanical construction

The ZF compact power steering gear is based on a modular design, mainly consisting of three modules – a mechanical steering gear, a steering valve and a power cylinder.

The light metal housing (1) and the form-fitted cylinder tube (2) form the main body for locating the mechanical ratio system and the power cylinder. The rack (3) with the integrated piston (4) is guided in wear-free plain bearings. The pinion (5), which runs in bearings in the valve area, meshes with the rack teeth. The rack is pressed against the pinion by means of a spring-loaded yoke so that the teeth always mesh without play. A longitudinal bore in the rack guarantees air compensation between the two bellows chambers.

This bore is manufactured using a special forming technique. The pinion is connected with the valve body (7) through a torsion bar (6). The rotary motion of the steering wheel is transformed by the pinion into an axial motion of the rack. This motion is transferred to the steering arms by tie rods (9).

The ZF compact rotary valve (K-valve) – manufactured using a high proportion of extremely precise and economical production technology – is used in order to control the pressurized oil needed for power assistance. This valve design mainly comprises the valve body (7), which has eight control grooves in the valve bore, and a control bush (8) securely connected with the pinion (5). The surface area of the control bush has eight axial grooves that are matched to the control grooves in the valve bore.
The centering of the valve body (neutral position) is by means of a conventional or a positive center feel torsion bar (6) which is also the connecting element between the valve body, the pinion and the control bush.

The valve body and pinion run in anti-friction bearings to ensure the precision of operation and the functional safety of the steering valve, even at high pressures.

If a torque coming from the steering wheel or from the steered road wheels is transmitted to the valve body or to the securely connected pinion and control bush, a relative rotary motion influenced by the torsion bar will occur between the valve body and the control bush.

The valve body is thereby caused to change its position in relation to the control bush inside it, so that the relative positions of the control grooves are changed, too. Pressurized oil can now flow through pipes to one of the two power cylinder chambers (ZL or ZR) and assists the axial movement of the rack if the turning motion is initiated from the steering wheel. If, on the contrary, the axial movement of the rack is caused by the road wheels, the steering valve will, in spite of the steering wheel being held, direct the pressure oil to that power cylinder chamber which counteracts the axial motion of the rack. This braking effect dampens road impacts.

When the steering wheel is released, the action of the torsion bar makes the control grooves return to the neutral position, and the same system pressure will exist in both of the power cylinder chambers.

ZF compact power steering gear, type 7891, with end take-off.

Compact rotary valve in neutral position.
The hydraulic fluid delivered by the steering pump (20) flows through a connecting bore in the valve area, via the feed oil radial groove (10) and transverse bores in the valve body (7), onward to the four feed oil control grooves (11) of the control bush (8). In the valve neutral position (fig. pages 10/11) the oil flows over the open feed oil control edges (12) to all valve body axial grooves (13) and onward, over the open return oil control edges (15), also to the return oil control grooves (14) of the control bush. From these grooves, the oil flows back via bores to the return oil chamber (16) and from there, via the hose, to the oil reservoir (21). At the same time, the radial grooves (17 and 18) of the valve body and their associated pipes provide for a connection between the right-hand (ZR) and left-hand (ZL) power cylinder chambers.

When turning the steering wheel clockwise (top fig.), the rack (3) with the integrated piston (4) will move to the right in the cylinder tube (2), (to the left in the installed position on the vehicle), if the pinion (5) is situated on top. Due to the simultaneous rotation of the valve body to the right, the pressurized oil is directed, over the further opened feed oil control edges (12), to the four associated axial grooves (13), via bores to the radial...
groove (18) and, via a pipe, to the left-hand power cylinder chamber (ZL), whereby the rack movement is hydraulically assisted.

An individually adaptable pressure build-up is achieved by the fact that the partially or fully closed feed oil control edges (12) restrict or prevent a connection between the pressure oil inlet and the other four axial grooves (13) connected to the radial groove (17). At the same time, the pressure oil outlet toward the pressurized axial grooves is restricted or prevented, too, by the closing return oil control edges (15). The oil displaced by the piston (4) from the right-hand power cylinder chamber (ZR) first flows through a pipe to the radial groove (17) and, through transverse bores, to the associated axial grooves and onward, over the further opened return oil control edges (15), to the return oil control grooves (14). From here, the further return flow of the oil to the oil reservoir (21) takes place via the connecting bores leading to the return oil chamber (16). When the steering wheel is turned counterclockwise, the operating sequence will be analogous to the above.

**Special equipment**

Like the other power steering gears made by ZF Lenksysteme GmbH, the ZF compact power steering gear can also be fitted with a number of equipment options in order to adapt it in an optimum way to the different vehicle kinematic and motorization conditions. In addition to the design features described on pages 7 to 9, the steering gear can be optionally fitted with three types of valve configuration. It is the modular design that makes this possible. The compact rotary valve, for example, is used when space limitations exist, and the standard rotary valve is used for relatively large oil flows. The Servotronic rotary valve with speed-sensitive control is used where best possible steering comfort is to be achieved.

**Schematic representation of the ZF compact power steering gear with various valve configurations.**

1 Compact rotary valve
2 Standard rotary valve
3 Servotronic rotary valve
ZF Lenksysteme GmbH: the systems partner

ZF Lenksysteme GmbH is one of the largest independent manufacturers of power steering systems for passenger cars and commercial vehicles. Renowned automotive manufacturers from all over the world value us as a creative and efficient systems partner for the development of new and innovative solutions.

As a joint venture of Robert Bosch GmbH and ZF Friedrichshafen AG, ZF Lenksysteme GmbH offers its customers a unique source of expertise when it comes to integrating a wide range of top technologies in modules, system modules or entire chassis systems.

The benefits for the manufacturer are clear to see: even shorter development times and optimized production processes – with quality standards which just get better and better.

ZF Lenksysteme GmbH
Richard-Bullinger-Strasse 77
73527 Schwäbisch Gmünd
Germany
Phone: +49 (0)71 71 / 31-0
Telefax: +49 (0)71 71 / 31-32 22
www.zf-lenksysteme.com