Technical Trends of Electric Power Steering Systems

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Koyo has provided electric power steering systems (hereafter EPS) into market for more than 10 years and recently EPS has been widely used. At first EPS was needed for such a vehicle model that required low fuel consumption or was difficult to equip a hydraulic power steering system. But now, EPS seems to be progressing to be a more safety and comfortable steering system due to the increase of needs for added value that can be satisfied only by EPS.

Herein, each EPS type and future technical trends on EPS are described.

Key Words*: electric power steering, EPS, trend, components*

1. Introduction

An electric power steering system (hereinafter referred to as EPS), has been increasingly used in many vehicles, especially in mini-sized vehicle market in Japan. The first marketing of the EPS was back to 1988, when Koyo introduced a column-type electric power steering system (hereinafter referred to as C-EPS) for mini-sized vehicles, in which a steering column was integrated with an assist mechanism driven by a DC motor.

With the increase of power-steering-equipped cars, more and more power steerings for compact cars have been required in Europe. As a result, EPS has begun to be used for many vehicles since 1996, especially for compact cars in which hydraulic power steerings are difficult to be mounted.

Since then, the use of EPS has expanded, resulting in the first US-made small SUV equipped with Koyo-made column-type EPS in 2002. EPS-equipped cars are expected to be increasingly marketed and will be used in North America, where medium and large-sized vehicles have been mainly used. Being combined with the current trend for environmental friendliness and energy-savingness, EPS will be the main stream of future power steering systems and an intense target of technology innovation.

Conventionally, EPS has been mainly required to be energy-saving and to provide easier installation into such vehicle models that hydraulic-type power steerings are difficult to be mounted. However, more and more EPS are now required to provide other advantageous functions that only EPS can offer, leading in a current trend for EPS that can contribute to safer and more comfortable driving. Hereinafter, EPS will be described with respect to the latest and future trends thereof.

2. Classification of EPS

EPS can be mainly classified into three kinds depending on the positions (e.g., a column part or other parts in a steering system of a gear part) to which an electric motor, a power source thereof, is attached, details of which are shown in **Fig. 1**.

Selection of EPS must be carried out based on the following two conditions.

(1) Required assist force

Assist force required to drive EPS is determined by: the rack axis force, which is determined by the axial load on both of vehicle front wheels as well as the suspension structure including tires; and the manual input by a car driver. Assist force calculated based on the above conditions needs to be used for the selection of the combination of a motor and a reduction gear that can provide an output suitable for the required assist force.

The selection of the combination of a motor and reduction gear as a power source function, however, has a limitation in that the size of the two components is required to be small enough to be accommodated in a specified space. This is because the existence of space requirements described hereinafter. This is also because of the limitation on available voltage for EPS, by which for-vehicle power source voltage is limited to 12V. This means that EPS can be used only for compact cars which consume smaller amount of electricity and this also means that another for-vehicle power source voltage of 42V must be used in order to allow EPS to be used for vehicle models having heavier weight. Another limitation on the selection of EPS for medium and large-sized vehicles is the strength of a rack & pinion gear part. That is, in a steering force transmission system of a hydraulic power steering, driver's steering force is input through a mechanical part responsible for transmitting manual input to be combined with a hydraulic assist driving force and then is sent to a hydraulic cylinder to directly reach a rack axis. In C-EPS and pinion-type EPS (hereinafter referred to as P-EPS) on the other hand, both of a driver's steering force and a assist force are simultaneously transmitted to a rack & pinion part, requiring a

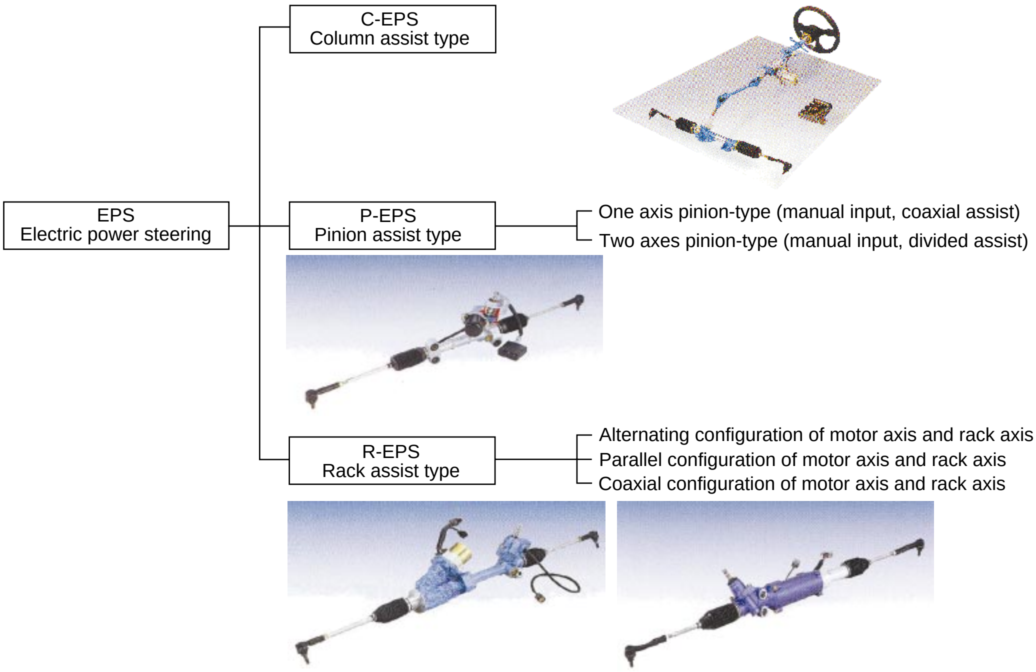

Fig. 1 Classification of EPS

designer to cautiously consider the teeth strength of C-EPS and P-EPS. In order to eliminate the above limitations, Koyo has newly developed a rack-type EPS (hereinafter referred to as R-EPS), which has a double speed reduction-type reduction gear mechanism. In this R-EPS, the input to a rack & pinion part can be reduced by providing an assist force to a rack axis directly from a reduction gear part, allowing R-EPS to be used for medium and large-sized vehicles.

(2) Space for mounting EPS

EPS system includes a motor and a reduction gear, which are relatively large and heavy. Thus, mounting EPS to a steering system in a vehicle's front space, a conventional layout of which typically has been intended for a conventional hydraulic or manual steering system, must be carefully performed by selecting a suitable layout in which EPS can fit into the space. Mounting EPS also must be carried out so that energy absorption by a column part and a crushable zone in an engine can be maintained and heat generated by EPS-mounted portions adjacent to the engine has no effect on the engine room.

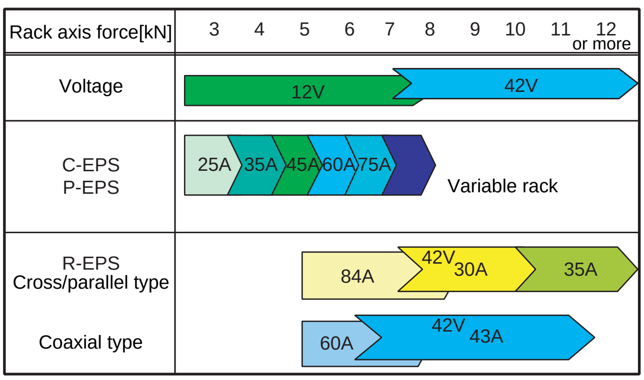

Fig. 2 Classification of EPS based on rack axis force

Figure 2 shows the general classification based on which applications of Koyo EPS and motor current/voltage are selected depending on the rack axis force thereof.

The above classification, however, is not applicable to an exceptional case where some requirements such as those for steering responsiveness require an EPS to provide a motor having an output that is larger than the axis force.

3. Technical Trends for C-EPS

The structure of C-EPS is, as shown in **Fig. 3**, is provided such that the C-EPS mounted on a column axis provides an assist force to a column shaft via a worm gear.

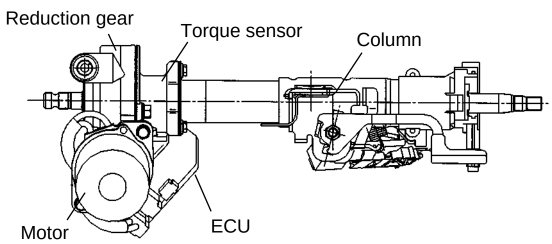

Fig. 3 C-EPS

This assist force is provided by the current control to a motor. That is, the optimal value of a current required for a motor is calculated by Electronic Control Unit (ECU), based on an electric signal from a torque sensor and a signal from a vehicle speed sensor. The torque sensor sends the signal depending on a torsional angle of a torsion bar mounted in the inner part of a column axis, which is proportional to a steering force. The vehicle speed sensor is provided on a vehicle side (normally a transmission side).

ECU can be classified into two types; one is mounted in a vehicle interior and the other is mounted on a column (**Fig. 3**).

Among the two types of ECUs, the column-mounted-type ECU is increasingly used due to its advantage of allowing shorter harness and other wirings and smaller number of vehicle mount processes. This column-mounted-type ECU has an another advantage of being provided in a vehicle interior where the space for mounting a motor and a reduction gear can be secured with relative ease, allowing it to provide easier replacement for a hydraulic-type power steering and to have an experience of being used in some small vehicles when they had minor design changes. The column-mounted-type ECU is also expected to be used in medium-sized vehicles, thanks to the development of a motor providing both of compactness and large output and the use in a manual gear of a variable gear ratio-rack having lower gear ratio in the middle portion thereof and higher gear ratio in the side portions thereof (**Fig. 5**). The column-mounted-type ECU has further advantage of low-cost enabled by the fact that it does not need any particular water-proof or heat-preventive measure for electric devices, allowing it to have the structure providing the lowest cost and to be mass-produced in the amount larger than that of any other types of ECUs.

The column-mounted-type ECU, however, has one challenge; its structure in which a column axis has thereon a reduction gear and a torque sensor limits a space for absorbing a collision energy. This may require a column-mounted-type ECU having a new structure which can satisfy newly-established collision safety requirements in Europe.

Recently, more and more C-EPSs are modularized with an ignition switch, automatic transmission selector, and a bracket for a switch lever, or are systemized with an intermediate shaft and a manual gear developed by a single supplier, an example of which is shown in **Fig. 4**.

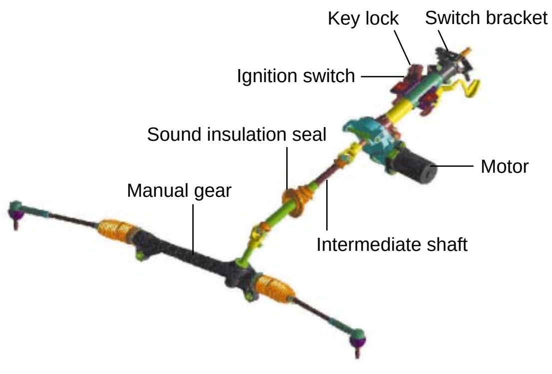

Fig. 4 Modularized C-EPS system

Fig. 5 Variable gear-ratio rack bar

4. Technical Trends for P-EPS

P-EPS has a structure as shown in **Fig. 6** in which a rack & pinion-type steering gear has a motor which generates an assist force via a worm reduction gear mounted on a pinion axis to a pinion shaft. The basic structure of P-EPS, including the reduction gear and the torque sensor, is similar to that of C-EPS but is different in its mounting position; P-EPS is mounted on a lower part of an engine room adjacent to which exhaust pipes of the engine may be run. Accordingly, P-EPS must be made of materials and has a structure which are superior in heat resistance and water proof. Most of ECUs of P-EPSs have been conventionally attached inside of a vehicle. This attachment position, however, requires long harness and thus may cause radio noise or may require an automobile maker to have an increased number of assembly steps. Thus, more and more P-EPSs are currently mounted inside of an engine room or are integrated with gears, which means extremely severe operating conditions for ECU and thus may require an additional heat insulator.

Currently-used P-EPSs have another difference from conventional ones in that a motor and an ECU are heat-controlled by a thermistor in addition to conventionally-used current and time control. That is, a thermistor is attached to an ECU or an amplifier of a torque sensor to provide sensitive control to P-EPSs, thereby providing an increase in time until which assist force begins to decrease and a reduction in time until which assist force is recovered[2)]. When an excessive reverse input, such as the one generated when a vehicle runs onto curbstones, is send to a P-EPS, this excessive reverse input is transmitted via a rack & pinion gear to a resin reduction wheel of a reduction gear. This is disadvantageous as compared to C-EPS that has an intermediate shaft in the middle of the structure because such a reverse input can be absorbed by the intermediate shaft of C-EPS, which is impossible for P-EPS which has no such an intermediate component. The result is that some P-EPSs have torque limiters therein for protecting resin gears. The structure of P-EPS, however, has another advantage in that its manual-type column can provide wider space for accommodating a collision energy absorption mechanism, allowing more P-EPSs to be used in for-European market cars. Some of currently-used FF vehicles, which have compact engine rooms, require a P-EPS to have a different structure; the compact engine room means limited space for mounting P-EPSs and more strict conditions for obtaining a crushable zone in a vehicle front part. An answer to this limitation is a double pinion-type structure in which an input from a steering wheel and an assist part are divided, two pinion shafts are provided, and a reduction gear and a motor are provided on a passenger seat side.

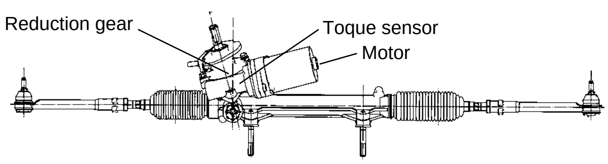

Fig. 6 P-EPS

5. Technical Trends for Rack-type EPS (R-EPS, DD-EPS)

More EPS are now mounted on medium and large-sized vehicles, reflecting the increase in needs for more energy-saving vehicles. C-EPS and P-EPS, however, are limited in their applicability to medium and large-sized vehicles because they have limited strength for rack & pinion parts to accommodate large input. Koyo solved this limitation by providing a rack type EPS which has a reduction gear of double speed reduction-type. The rack type EPS has a structure in which a reduction gear directly assists a rack axis to reduce the input to a rack & pinion part, allowing it to be suitable for the application for medium and large-sized vehicles. The rack-type EPS can be classified into two types; one type has a structure as shown in **Fig. 7** in which a motor is offset from a rack axis (R-EPS) and the other type has a coaxial structure as shown in **Fig. 8** in which a motor axis has a hollow shaft through which a rack axis is provided (DD-EPS).

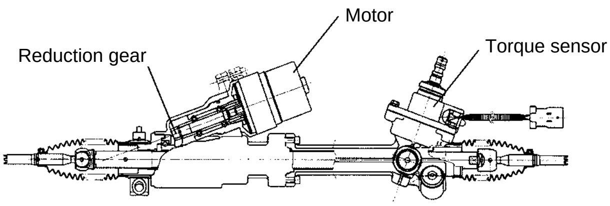

Fig. 7 R-EPS

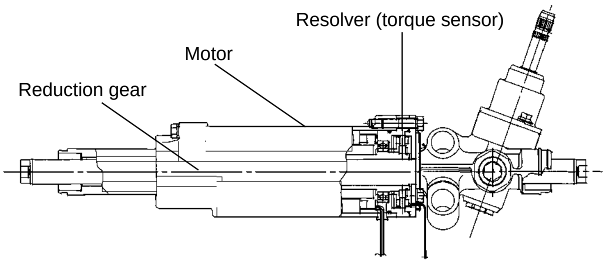

Fig. 8 DD-EPS

R-EPS provides an assist force by the following structure. A motor mounted on a rack & pinion gear part provides an assist force to a rack bar via a double-speed type reducer which has a bevel gear-type speed reducer (cross type) or a belt-type speed reducer (parallel type) and special designed screws formed on a rack axis. This structure for providing an assist force allows R-EPS to have motor components which are common to those for other steering systems, except for the motors for C-EPS and P-EPS and the shaft, and to provide wider selection of attachment angle and position of a motor, resulting in R-EPS that can be attached to wide range of positions.

DD-EPS on the other hand provides an assist force by the following structure. A motor provided in a rack housing provides an assist force to a rack bar via a motor axis and specially designed screws. This structure in which a rack can be entirely accommodated in a motor provides DD-EPS with more compact structure. However, DD-EPS having larger output needs increased rack diameter and larger motor components and thus results in an increased outer configuration of an entire housing, which may cause an interference with a transmission part or an engine oil pan.

Despite of the above concern, DD-EPS is still an ideal system which can provide high speed reducer efficiency, so long as a vehicle intended for DD-EPS is developed by properly considering its packaging with DD-EPS from the start of the design development.

If a for-vehicle power supply voltage of 42V can be obtained, a rack-type EPS can provide the significant increase of a motor output, allowing it to be used in larger vehicles[1)].

6. Additional Requirements for EPS

Conventional EPS systems have only been required to be a replacement for hydraulic power steering systems. Currently-used EPS systems, however, is additionally required to work as a part of integrated systems for controlling a vehicle, including those under development shown below. Further discussions on safety will be needed for the feasibility of such integrated systems. EPS will be a key to the feasibility because such an integrated system cannot be realized until EPS can be adapted to peripheral techniques for such integrated system by providing new functions or allowing the data from the sensor to be shared by other systems.

<Future integrated vehicle control systems>

①Automatic parking system by which various data such as a vehicle steering angle, position information, and speed of a vehicle can be used to park the vehicle automatically.

②System for preventing a vehicle to deviate from a lane by which a lane and a vehicle speed can be monitored to support the driving of the vehicle in the straight line.

③Automatic light distribution system by which steering angle signals from EPS can be used to light vehicle headlights accordingly.

Figure 9 shows the summary of the EPS-related future technical trends described above.

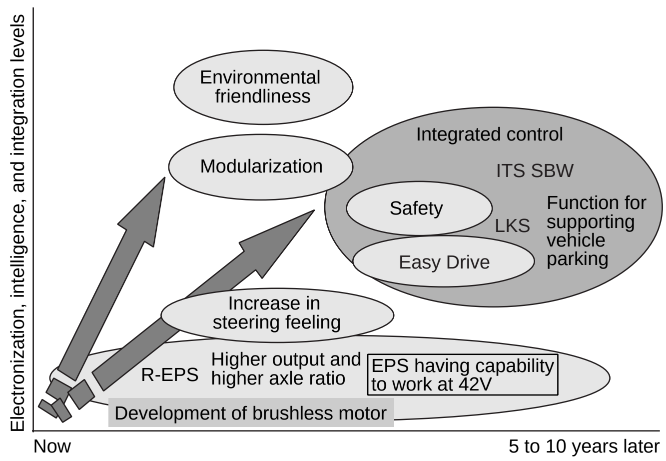

Fig. 9 Future trends for EPS

7. Conclusion

As described above, the trend mainly in Europe for using vehicle power source voltage of 42V gives EPSs an opportunity to be used in medium and large-sized vehicles. EPS is given another opportunity to be used in large vehicles by the increased use of absolute steering angle sensors which are needed for a vehicle stability control function. That is, the data regarding steering angles and tire direction inputted by the absolute steering angle sensor can be used to easily develop additional functions for EPS, allowing more EPSs to provide other new functions such as the function for optimizing steering control, automatic light distribution system for vehicle headlamps, a system for preventing a vehicle to deviate from a lane, a function for controlling vehicle backward motion, and automatic parking function.

As described above, EPS is and will be an important component for a vehicle which can contribute to a safer and more comfortable vehicle by sending steering-related information.

References

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