Product Introduction

Development of High Power Output 2 pinion EPS

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1 Introduction

Electric power steering (hereinafter referred to as "EPS") is currently utilized in many passenger cars, and the EPS installation rate has been increasing every year. The main reason for its utilization is improvement of vehicles' fuel efficiency, but the steering feeling improvement and high output design are also contributing to its utilization increase. EPS systems using various methods according to vehicle characteristics for a wide scope of vehicles from compact vehicles to large vehicles have been developed and installed. We have developed 2 pinion EPS and started mass production of them in KYB Gifu North Plant (Fig. 1) in 2016. We would like to explain the characteristics of the 2 pinion EPS in the next section.

2 2 pinion EPS

KYB was the first manufacturer in the world to start mass production of 2 pinion EPS in 1989.

Since then, we have been mainly developing and mass-producing pinion types by adding 1 pinion EPS to the product lineup. The 1 pinion type has an assisting mechanism on the handle shaft. They are generally compactly structured with a small number of components. However, the area around the handle shaft is enlarged, resulting in mountability issues in some cases. In addition, due to the fact that all of the steering force from the driver and the assisting force from the motor is supported by one rack & pinion, the load on the rack & pinion grows greater if high output is required.

On the other hand, the 2 pinion type has 2 different shafts for the handle shaft and assisting shaft. The handle shaft consists of the torque sensor section, which detects the input torque from the driver, and the rack & pinion, which transmit the steering force. The assisting shaft consists of the worm reduction gear section, which decelerates motor rotation, and the rack & pinion, which transmit the assisting force. Due to this, we can make the handle shaft area size smaller than the 1 pinion type. Furthermore, the right/left position and the rotational phase for the assisting shaft can be freely set, achieving great mountability. By utilizing this flexibility along with high-output motor and high reduction ratio, we can establish high-output EPS over 10kN.

Another advantage is its direct and natural steering feeling, due to the fact that the handle shaft doesn't have an assisting mechanism so that the assisting force is directly applied to the rack.

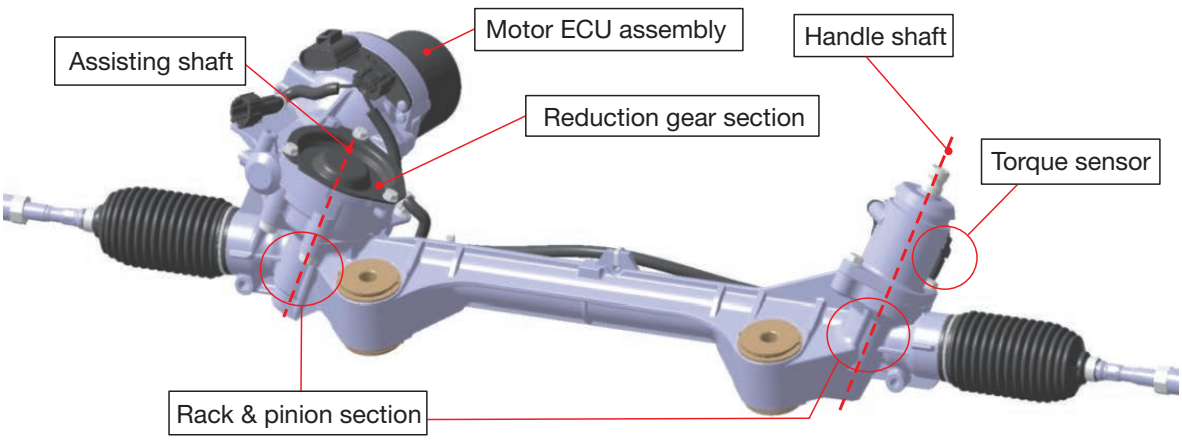

Fig. 1 2 pinion EPS

3 Product Introduction

It's been more than 25 years since KYB started mass producing 2 pinion EPS. Based on the wide scope of element technologies that we have accumulated in the course of this period, including utilization of brush-less motors, high output design, silence, improvement of steering feeling, and the addition of a wide variety of control specifications, we developed the system of this product by focusing on the following items:

① High output design
② Improvement of silence
③ Improvement of safety
④ Improvement of steering feeling

Key specifications of this developed product are shown in Table 1.

Table 1 Key specifications

Item	Specifications
Motor type	DC brush-less
Steering method	Rack & pinion
Theoretical thrust	9.6kN
R & P gear ratio	44.66mm/rev
Reduction gear ratio	1/15.5
Rack stroke	134.4mm
Rack diameter	ø28

3.1 High Output Design

High output design increases the load on the rack & pinion and reduction gear, so strength and durability improvement are required.

As a measure for the rack & pinion, we improved the durability by increasing the rack diameter. We also used a material with high abrasion resistance for the pressure pad seat, which is a sliding part that supports the rack.

Since there was not enough space between the reduction gear and peripheral vehicle components, the reduction gear had to be made compact. We were able to achieve this by maintaining a small reduction ratio. In order to achieve the contradicting requirements of a small reduction ratio and high output design, we needed to increase the motor torque, resulting in an increased load on the reduction gear. Therefore, we decided to use an injection-molding worm wheel using a new material (Photo 1) to respond to the strength and durability improvement. Furthermore, we optimized the reduction gear profile through FEM analysis to improve durability.

3.2 Improvement of Silence

Demands for EPS silence continue to increase along with the improvement of comfort in vehicle interiors, and we needed to reduce operation noise.

Photo 1 Injection-molding worm wheel

Fig. 2 shows the rack & pinion section and the stroke stopper section. With the rack & pinion section, we reviewed the specifications of the rack and the pressure pad that supports the rack to simultaneously achieve durability and silence. In addition, we placed a resin damper ring between the gear box, which is part of the stroke stopper section, and the inner joint assembly to reduce the impact noise from contact.

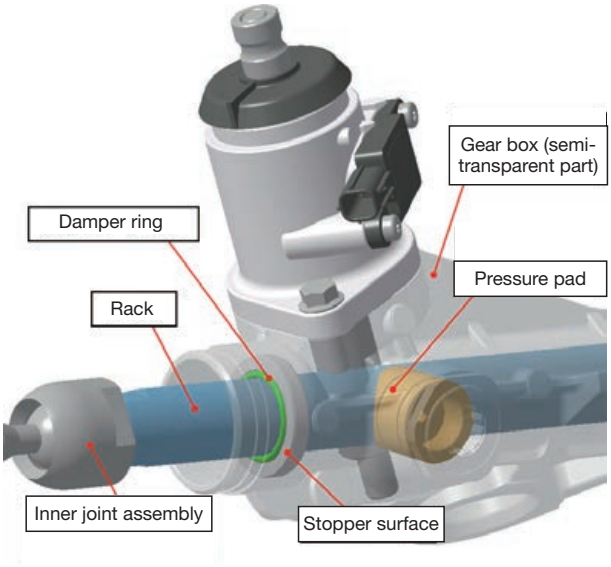

Fig. 2 Rack & pinion, stroke stopper section

Fig. 3 shows the worm reduction gear section. We stabilized the backlash from the worm and the worm wheel with the adjustment mechanism using a spring and coupling to reduce the reduction gear noise.

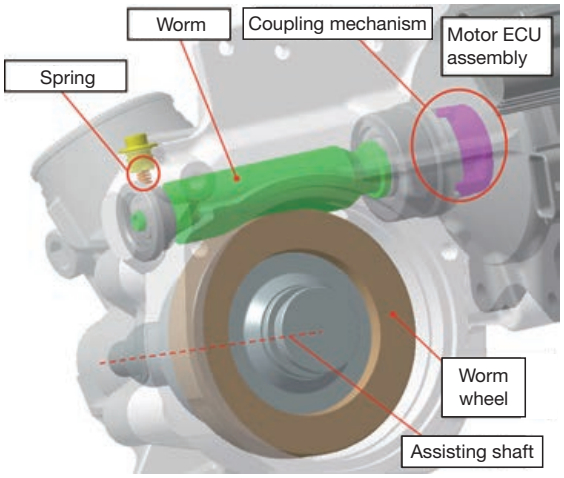

Fig. 3 Reduction gear backlash adjustment mechanism

3.3 Improvement of Safety

In recent years, there have been more demands for ISO26262 compliance as functional safety response, due to the heightened interest in safety.

ISO26262 is a functional safety standard for vehicles issued in November of 2011 as an international standard.

The EPS system is in charge of "turning", which is one of the 3 basic functions of vehicles, and the required safety level is extremely high. Due to this, system safety is positioned as the highest priority issue in development.

The ISO26262 standard provides the definition "Absence of unreasonable risk due to hazards caused by malfunctioning behavior of Electrical/Electronic systems", so the risk due to failures of electrical/electronic systems on vehicles must be reduced to a socially-acceptable level. Representative hazardous modes include self-steering, in which the handle moves regardless of the driver's intention, and steering lock, in which the handle does not move when the drive wants to steer.

The safety level required in electrical/electronic systems is defined by ASIL [Note 1)]. Each hazard caused by malfunctioning behavior of systems is assessed according to the 3 indexes shown in Table 2 and is categorized into 4 ASIL levels from "A" to "D" (Fig. 4). The development of the EPS system was required to achieve ASIL D, which is the strictest level.

In order to achieve functional safety, we are required to apply processes in accordance with the standard. Due to this, we newly established an internal development process in accordance with the standard and promoted the following activities based on the process:

① Failure mode analysis
② Refinement of safety requirements to the technical level
③ System design that satisfies the refined safety requirements
④ Development of safety mechanism that detects abnormalities and shifts to safe status
⑤ Verification of the system's safety requirement achievement level
⑥ Tests from perspectives required by the standard
⑦ Functional safety assessment

In addition, a safety mechanism to thoroughly detect system abnormalities that can cause hazards is also required. Due to this, we newly applied the redundant monitoring method used to enhance microcomputer monitoring mechanism to this system (Fig. 5).

Table 2 ASIL determining indexes

Index	Description
Severity	Extent of failures caused by malfunctioning (serious injury, minor injury, etc.)
Exposure	Frequency of the operation situation (situation in which the vehicle travels at high speed, etc.)
Controllability	Likeliness of being able to avoid the hazard (most drivers can avoid the hazard, etc.)

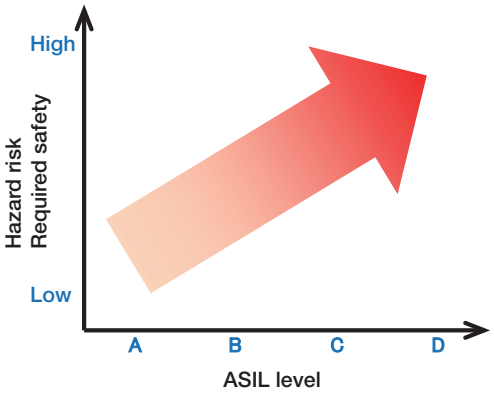

Fig. 4 ASIL levels, risk, and required safety

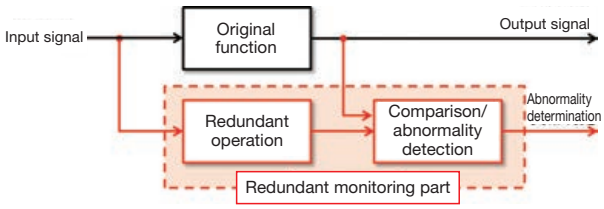

Fig. 5 Redundant monitoring block diagram summary

As a result, we confirmed in the functional safety assessment that the development was promoted by correctly applying the required development process and that the system satisfies the safety requirements by customers.

Note 1) Short for "Automotive Safety Integrity Level". This is a safety level standard for automobiles.

3.4 Improvement of Steering Feeling

The following control parameters were applied to this vehicle:

① Basic assisting control
② Phase compensation control

③ Damping control
④ Friction compensation control
⑤ Steering wheel return control

As a result, we were able to achieve the optimal steering feeling for the vehicle.

4 In Closing

We can say that the 2 pinion EPS is a product that can balance the performance required in EPS, such as high output, vehicle mountability, and steering feeling, at a high level. We expect that the demands will grow further in the future.

Through this development, the 2 pinion EPS has achieved high output design as well as improvement of silence, safety, and steering feeling. We would like to express our appreciation for everyone who has provided us with their cooperation in the course this development.

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