Technology Introduction

Development of Electric Power Steering Evaluation System

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1 Introduction

With the recent worldwide voice for environmental considerations, the automobile industry has rising expectations for electric vehicles (hereinafter "EVs").

The U.K. and France announced to ban the sales of internal combustion engines by 2040. When I visited the 2017 Frankfurt Motor Show, I could not help being aware of the oncoming of the age of EVs.

Furthermore, the development of autonomous cars has rapidly advanced throughout the world. Recently in Japan, I have sometimes heard news about autonomous car driving tests on public roads.

As the development of EVs and self-driving technology advances, it is urgent to improve the performance and reliability of electric power steering (hereinafter "EPS") technology.

The Experiment Section is addressing the development of evaluation techniques and test equipment with the aim of improving experiment reliability and efficiency as in the product development.

Like the pump experiment equipment introduced in KYB Technical Review No. 55, this article introduces efforts by the Experiment Sect. focusing on the development of an EPS evaluation system.

2 Product Introduction

2.1 What is EPS?

EPS is a system intended to reduce the driver's effort in steering with the assistance of an electric motor.

EPS takes various forms and can be roughly classified into:

① Column assist type
② Pinion assist type
③ Rack assist type Note 1)

Note 1) The rack assist type can be further divided into direct drive, belt drive and dual pinion types. For the purpose of this article, the rack assist type is referred to as "dual pinion EPS".

The dual pinion EPS (Photo 1), which is one of the major products of KYB, is often installed at the lowest position in the engine room. The dual pinion EPS may be exposed to heat from the engine or muffler. On the other hand, vehicles equipped with EPS are also delivered to areas with an extremely cold climate. EPS must endure rapid temperature change and needs to guarantee the operation in a wide temperature range from 120°C to -40°C.

EPS may also be exposed to muddy water or contaminated water that has melted from the road deicer during winter. Under extremely severe service environments like these, EPS is required to have higher waterproof and rustproof properties.

Once a car accident occurs, EPS may be alleged to have caused the accident and could be the focus of a suit. Thus, EPS is naturally required to meet stringent reliability test requirements. It is also necessary to visualize phenomena related to EPS.

Furthermore, drivers feel the performance of EPS directly with their "hands". In this sense, EPS is a component whose sensory performance like "steering feel" is tested.

Under the situation, we have promoted the development of KYB's original testing system for the purpose of establishing a test bench that can exactly reproduce severe test conditions, quantifying the sensory performance and visualizing phenomena.

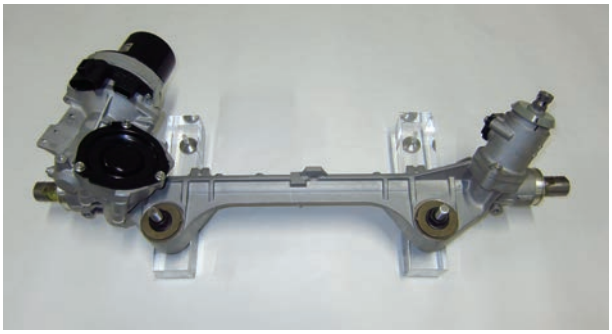

Photo 1 Dual pinion EPS

2.2 EPS structure and operation

Before getting down to the subject, this section explains

a little bit more about how the Dual pinion EPS works.

EPS generally consists of the components shown in Fig. 1. The operating sequence is as follows:

① Driver operates the steering wheel.
② The wheel steering power (hereinafter "steering torque") is received by the stub shaft.
③ The torque sensor detects the steering torque.
④ Torque signal is sent to the ECU Note 2).
⑤ ECU supplies power to the assist motor according to the torque signal.
⑥ The reduction gear augments the torque from the assist motor to provide steering assistance.
⑦ The torque is transferred to the pinion gear that is integral with the reduction gear. The rotary motion of the pinion gear is converted into a linear motion by the rack & pinion.
⑧ Thrust generated by the rack is transmitted via the tie rod to push the knuckle arm, generating a steering angle for the tires.

By repeating the sequence above, EPS will assist driver in steering.

Note 2) Stands for Electric Control Unit.

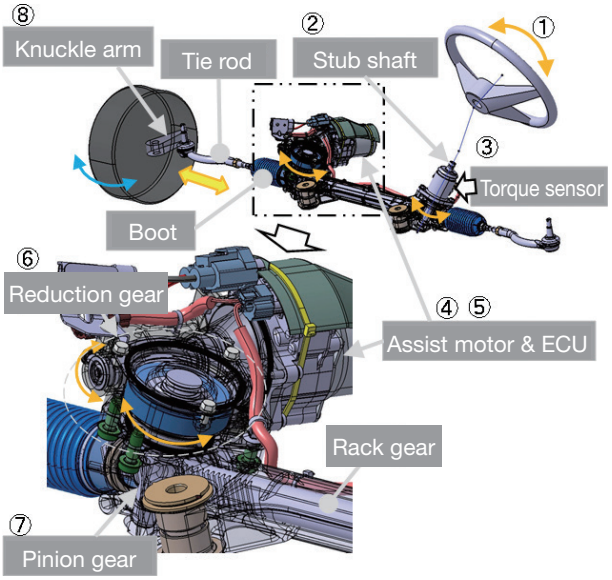

Fig. 1 Components of Dual pinion EPS

3 Introduction of Testing Systems

3.1 Muddy salt water resistance testing machine

3.1.1 Development background and overview

As described in the product introduction section, this is a testing machine that carries out an endurance running test on EPS while pouring muddy salt water over them in order to evaluate rustproof and sealing properties.

To guarantee the safe operation of EPS, it is particularly important to ensure the sealing performance to prevent the exposure of the motor and ECU to water.

For example, the boot, which is designed to expand or contract by steering, may have negative inner pressure to absorb water from the outside.

This example implies that only the simple water immersion or sink test is not sufficient. Rather, spraying muddy salt water over EPS while steering is a way of evaluating rustproof and sealing properties under most conditions similar to the actual situation.

Previously, the sealing property evaluation test using muddy water was carried out independent of the rustproof property verification test using salt water. However, another need of verifying the resistance to the road deicer or snow melting agent scattered on roads during the winter season also arose. Furthermore, in the previous sealing property evaluation test using muddy water, a suitable simplified water tank was prepared for each test sample. This test involved some problems that salt water spilled and that the mist containing salt water caused salt damage to the surrounding of the test area.

With considerations given to these problems, this testing system has been developed. The new system can provide endurance operation of EPS by giving the tire reaction and steering torque from the steering wheel to the right and left tie rods while spraying muddy salt water of a specified concentration over the sealed sections of EPS.

3.1.2 Features of testing machine

(1) Automatic control of muddy salt water concentration

It takes about one to two months for an endurance test to be completed. To prevent any variations in concentration of the muddy salt water for spraying due to evaporation during the test, the testing machine features the automatic concentration control function that monitors the water level in the water spray tank and automatically controls the concentration by automatic water supply.

The water in the tank is continuously mixed by a jet to prevent sedimentation of mud.

(2) Rust prevention of the system

Since the spray water contains salt, the test chamber of the system is made of stainless steel to prevent rust of the system itself. The chamber encloses the test sample EPS. Still, small amounts of water vapor containing salt leak from the chamber. Then, the chamber is further surrounded by another stainless steel casing to make up a double structure. Ventilation fans to release the vapor to outside are also installed.

(3) Effluent filtering

The used muddy water contains salt. For environmental consideration, a filtering mechanism to remove the salt content is installed on the discharge side.

(4) In-chamber washing mechanisms

After testing, any scattered muddy salt water is deposited on the inner surface of the chamber. The two washing functions listed below are provided for easy maintenance of the system.

① A spray nozzle for automatic washing is provided on the chamber roof (Photo 2).
② A high-pressure cleaning gun is installed for easy removal of precipitated salt.

(5) Test observation

The test chamber needed to be of enclosed type in order to protect other test equipment in the test room. However, the enclosed test chamber made it impossible to visually check the internal test conditions.

Providing an observation window was an option, but it was easily expected that the window would be dirty with mist deposit for instance, making it impossible to visually check the test progress. Then, a CCD camera was installed in the test chamber to allow operator to see what was going on inside the chamber (Photo 3).

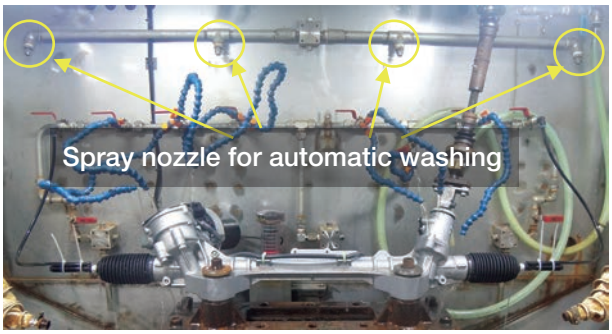

Photo 2 Internal of muddy salt water endurance test machine

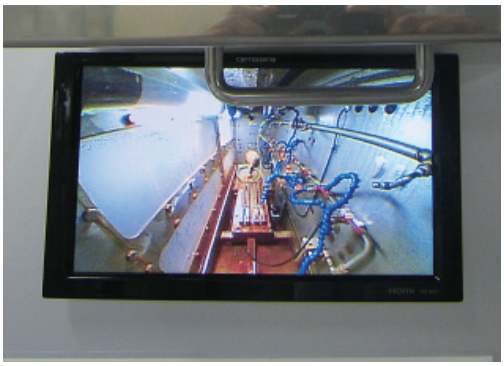

Photo 3 Image of testing machine internal captured by CCD camera

3.2 Rack bend testing machine

3.2.1 Development background and overview

This testing machine is used to verify the load with which the steering system fails when the vehicle hits a curbstone or other obstacles.

The steering system is an important vehicle component to take charge of "turning", which is one of the three major elements of vehicle movement: run, turn and stop. It should be avoided until the end that the steering system no longer functions.

To protect the steering system, a mechanism has been provided that, in case of an accident such as hitting a curbstone, causes the suspension parts to fail first to keep the steering parts from being damaged.

The purpose of the rack bend testing machine is to verify that the steering system has higher rigidity and higher strength than these suspension parts.

Conventionally, it was necessary to prepare a special test jig (frame) for each vehicle model so that the on-vehicle layout can be reproduced for testing. Now this is no longer necessary thanks to the developed testing machine.

3.2.2 Features of testing machine

To satisfy the requests by automobile manufacturers, the testing machine has the following features to verify the strength of the EPS installed and used under various conditions:

(1) Horizontal tension and compression mechanism

Since general tension and compression testing machines apply a load in the vertical direction, EPS samples have to be set in such machines with poor workability. KYB's rack bend testing machine in turn is designed to apply a load in the horizontal direction and to secure EPS on a horizontal surface plate for improved workability.

(2) Higher degree of freedom in loading angle

The test is conducted on various vehicle models under various situations. This means that the testing machine must support a wide range of load input angles. The load point of EPS is the inner ball joint in the rack end. Loading orientation varies by specification. In addition, EPS is an oscillating component, so its properties may vary by the section modulus of the rack and/or bend angle of the tie rod.

To allow the operator to easily set the specified load input orientation, the fixed part of EPS uses a rotary table for flexible adjustment. In addition, a mechanism for setting the crosshead position by sliding laterally is provided (Photo 4).

(3) Double screen display

A display screen is provided for controlling the testing machine and another for data logging to allow the operator to easily view the operation and instantaneous data.

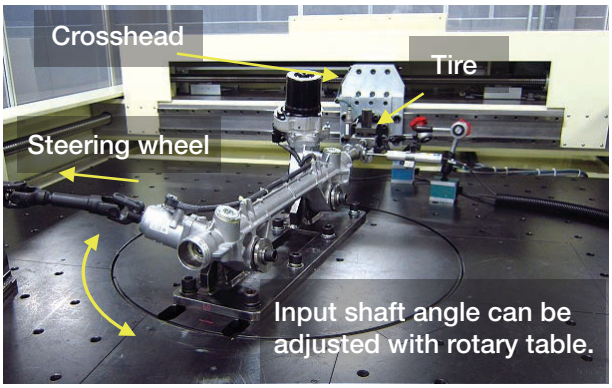

Photo 4 Rack bend testing machine

3.3 Reduction gear endurance testing machine

3.3.1 Development background and overview

The reduction gear is an important vehicle component and may be considered as the heart of EPS. The reduction gear is mainly made of plastic for various reasons including unusual sound control, strength and elasticity. Plastic

gears are so delicate that accuracy depends on atmospheric humidity.

This testing machine has been developed to reliably identify any changes including microcracks occurring during endurance running and performance variations caused by overheating (Photo 5).

A testing machine that can flexibly adjust the shaft crossing angle was also needed to develop the angular reduction gear, which is one of the featured products of KYB. The angular reduction gear has a benefit of improving the degree of design freedom in on-vehicle layout.

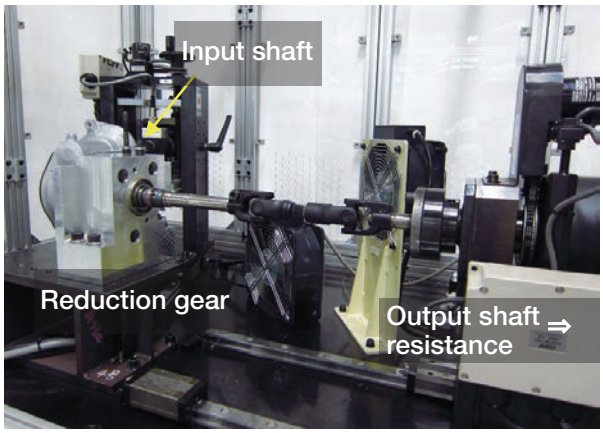

Photo 5 Reduction gear endurance testing machine

3.3.2 Features of testing machine

(1) Automatic stop after minute torque variation

The machine is designed to be stopped when a minute torque change (variation) on the input side is detected. This function helps determine the breakage initiation of the gear, leading to proper identification of the cause of breakage initiation.

(2) Higher degree of freedom in test condition adjustment

This testing machine allows seamless adjustment of the shaft crossing angle and loading torque adjustment in minute increments.

(3) More accurate control of input shaft rotation angle

When the reduction gear (worm wheel) of EPS rotates three to four turns at most, it will reverse the direction of rotation as it shares the shaft with the steering wheel. The testing machine is designed to be able to faithfully reproduce this reversing during an endurance test. However, the reversing point, if it is fixed at the same point, will have a highly concentrated load and the gear will start to break at the reversing point in many cases.

In an actual vehicle, a gear always having the same reversing point never occurs. Therefore, an action is needed to provide two or more reversing points depending on the actual operating conditions.

The newly developed endurance testing machine can closely control the rotation angle of the input shaft, thereby allowing distributed reversing points. Thus, the endurance test can be conducted in a similar way to the actual situation.

3.4 Unusual sound evaluation testing machine (evaluation of inversely input unusual sound)

3.4.1 Development background and overview

Since EVs run silently without issuing engine sound, the requirements for EPS "sounds" (such as operating sound, control sound and rattle sound [Note 3)]) have become more severe.

Vehicles are also likely to deteriorate earlier when they run under a high- or low-temperature environment depending on the destination. The need for identifying the source of unusual sounds, the sound level and cause of the sound quickly and exactly led to the development of this testing system.

Note 3) Refers to the "tooth hammer" that may occur in the gear section. The rattle sound may cover all kinds of "hammers" if the cause is unclear.

3.4.2 Features of testing machine

(1) On-bench reproduction of running vehicles

The unusual sound evaluation system (Photo 6) was developed to achieve on-bench reproduction and evaluation of unusual sounds equivalent to actual ones by applying vibration with a tire input load of an actual value measured during driving on a bad road.

[Vibrating procedure]

① Install an inertia plate equivalent to the steering wheel on the input shaft.

② Vibrate EPS using a shaker via the tie rod.

The system can acquire the measured waveform during actual running at high sampling frequencies, making it possible to reproduce the vibration more similar to actual vehicle conditions.

To faithfully reproduce vibration with unusual sound of product, a low-friction seal cylinder is used.

This helps cancel the cylinder sliding load and vibration of the testing machine due to the cylinder seal.

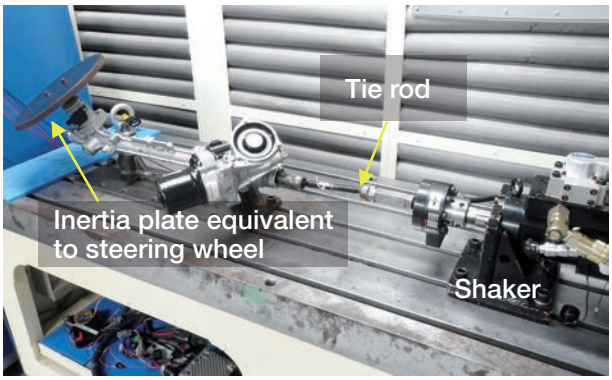

Photo 6 Unusual sound evaluation testing machine

(2) Automated measurement

To obtain stable measurement results, the feedback control that automatically adjusts the input load to a specified value has been included in the control program.

Furthermore, the procedure from the test sample setting on the bench to vibration data measurement has been automated (Photo 7).

Photo 7 Display of automatic measurements

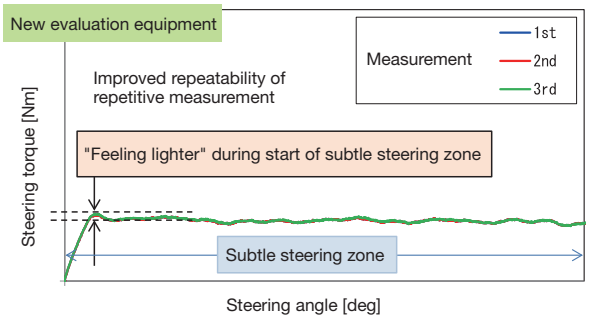

Fig. 2 "Feeling lighter" and repetitive measurement waveforms

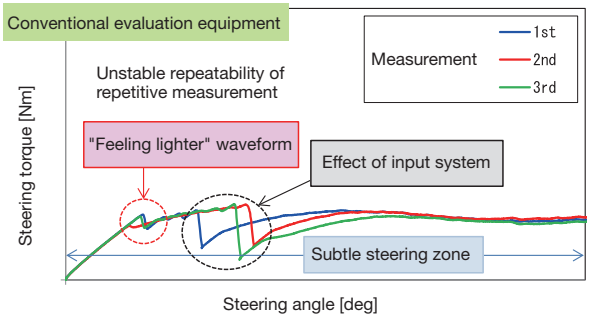

Fig. 3 "Feeling lighter" waveform obtained with conventional evaluation equipment

(3) Lower measurement variations and higher measurement accuracy

The system is designed to be allowed to carry out measurement only if the input load is within a specified range. These specification help reduce measurement variations and improve repeatability.

Now it is under discussion to allow the unusual sound evaluation test under a high- or low-temperature environment to meet the demand for on-bench reproduction of all types of environments similar to actual vehicle conditions.

3.5 System performance evaluation equipment

3.5.1 Development background and overview

In order for automobile manufacturers to be able to use KYB products in their next models, KYB proposes them to improve the steering feel. At this moment, evaluation of the steering feel is solely dependent on sensory evaluation by test drivers. To quantify the sensory performance, we are addressing the development of system performance evaluation equipment.

3.5.2 Quantifying the steering feel

We aim to evaluate driver steering feel by quantifying, for example, whether turning the steering wheel will smoothly change the steering torque or angle (no discontinuous change).

EPS tuning requirements depend on the vehicle specifications/concept or where the vehicle is delivered.

A recent challenge is to achieve a steering feel with which the driver can maneuver a vehicle only with a very minute steering angle, which leads to easy driving. As an example, the result of a measurement of "feeling lighter" Note 4) during the start of the subtle steering zone is shown below (Fig. 2).

Note 4) A phenomenon that the steering feel gets lighter at the moment when the vehicle starts to move as the driver has begun turning the steering wheel

3.5.3 Features of equipment

(1) Operation test in the subtle steering zone

For characterization of the subtle steering zone, it is very important to ensure the accuracy of the input shaft angle of the input system. The conventional input system (driven via the reduction gear) only worked unstably and could not reproduce the input shaft angle stably, making it difficult to achieve quantitative evaluation of "feeling lighter". Partly because of the input system motor inertia and ripple, the waveform of "feeling lighter" achieved through repetitive measurements showed variations (Fig. 3).

The newly developed evaluation equipment uses a direct drive motor type input shaft to enable stable operation in the subtle steering zone and high-precision control over the input shaft angle.

(2) Supporting complex steering patterns

An optional operation waveform program has been introduced to allow high-accuracy reproduction of complex steering patterns measured with actual vehicles.

The new equipment also supports angle control and torque control and can now flexibly respond to a variety of customer needs.

(3) Supporting steering system evaluation

For bench testing on the steering system, the layout equivalent to the actual vehicle, the input system, the column mount, the steering gear mount and the tire-equivalent loading device can be freely arranged on the surface table (Photo 8).

With these features, the equipment can accurately test the operation during the initial stage of the subtle steering zone including "feeling lighter" repeatedly on bench, which has been difficult to reproduce with any conventional equipment. The evaluation result can be quickly and accurately feedback to Design toward achieving higher product performance.

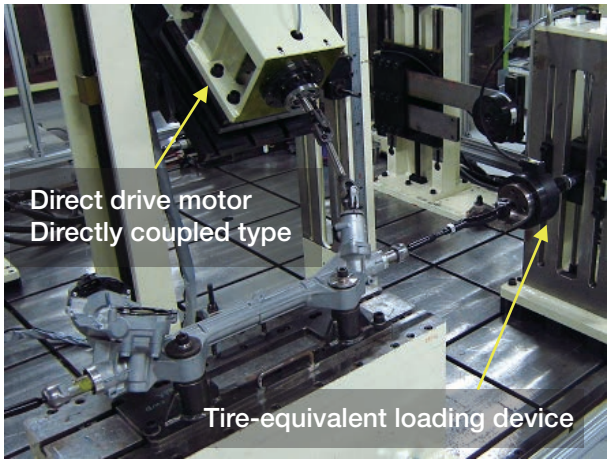

Photo 8 System performance evaluation equipment

4 Conclusions

The test equipment introduced in this article have been developed to achieve higher accuracy, higher reproducibility and higher efficiency. They can allow us to complete the series of evaluation tests prior to mass production in a shorter period than before as well as to obtain accurate test results.

We believe that this evaluation equipment will eventually help us deliver safer, more reliable products to customers.

There are still many challenges, but we would like to strive to develop and further improve evaluation techniques in addition to product development.

5 In Closing

With a focus on the development of EPS evaluation equipment, this article has introduced the efforts by the Experiment Dept.

To develop high-reliability, high-performance products, it is required to develop evaluation methods and improve measurement accuracy.

We are committed to raise our expertise and knowledge level and continue playing the role as the Experiment Dept.

Finally, on this occasion, we would like to deeply thank the affiliates and those concerned involved in the development of the testing machines as well as all those who extended guidance and support to us.

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