Development of Column Coaxial Steering Actuator for Commercial Vehicles

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The field of commercial vehicles is seeing expanding use of automatic operation systems and practical application of advanced driver assistance systems. We are developing a Column Coaxial Steering Actuator to meet increasing needs in this area. This actuator provides ADAS functions for large commercial vehicles, can be installed with minimal vehicle modifications, and contributes to both safety and comfort.

***Key Words**: steering actuators, commercial vehicles, ADAS, coaxial motor*

1. Introduction

In recent years, the pace of development for expanding the use of advanced driver assistance systems (hereafter "ADAS") and commercializing automated driving has been accelerating. However because the required output when steering in a large-size commercial vehicle is large, hydraulic power steering (HPS) is installed and support for ADAS is difficult with the functions of HPS alone. For this reason, development has proceeded of a column coaxial steering actuator (hereafter "coaxial steering actuator") that can actively control the angle for large-size trucks and buses that are equipped with hydraulic power recirculating-ball steering (RBS)[1). Because conventional column type electric power steering (C-EPS) uses a worm reduction gear structure, the motor protrudes from the steering column shaft, making it difficult to ensure space for the driver's feet. With this system, a hollow-shaft motor that does not require a reduction gear is installed coaxially with the steering column shaft, and a direct drive-type electric actuator is installed on the steering column. This allows ADAS functions to be added to a commercial vehicle with minimal vehicle design modifications in the steering column mounting part, achieving further improved quietness and good steering feel. This report introduces the development of a steering system that includes the world's first hollow-shaft motor installed coaxially with the steering column shaft.

2. Development Objectives and Issues

2. 1. Development Objectives

The following points were considered in the development of a system for commercial vehicles.

(1) Because commercial vehicles have a longer service life than passenger cars, the hardware has a redundant structure that allows software updates from Lane Keeping Assist (LKA) to Lv4 automated driving so that the vehicle can support future advances in automated driving without modification.
(2) A direct drive motor system was used in order to achieve high installation performance that can support large-size trucks and buses with wide variations in cabin and body types, including existing vehicles.
(3) Control technologies were constructed to reduce trade-offs resulting from system additions and improve steering performance (such as steering wheel return) in a system connecting a coaxial steering actuator and HPS.

2. 2 Development Issues

The difference between a coaxial steering actuator and conventional steering actuator (C-EPS) is that the former can be installed as an addition to a commercial vehicle equipped with EPS without major changes to the cockpit layout. With the C-EPS type, it is necessary to secure space for installing the motor. However because the coaxial steering actuator is installed coaxially with the motor, it can be installed without major layout changes. In order to achieve this, it is necessary to resolve the following issues.

(1) Increasing the torque of the hollow-shaft direct drive motor
(2) Ensuring space for installation of the electric actuator
(3) Improvement of control stability

(1) Because the system does not use a reduction gear, it is necessary to design a low-speed, high-torque motor.

(2) Shape design is necessary which allows installation in the space where the manual steering column is installed with minimal vehicle (design) modifications.

(3) Because of the structure with two torsion bars where the HPS and coaxial steering actuator each has a torsion bar, there is the possibility of vibration occurring in the steering torque. Because the HPS output status from the coaxial steering actuator is not known, there is the possibility of load fluctuations caused by changes in HPS output, and it is necessary to stabilize control of the steering actuator.

3. Development Concept

The development concept for this system is to enable the installation of the electric actuator while ensuring space around the manual steering column as much as possible in order to flexibly meet the demands for installing ADAS functions in commercial vehicles as described above. This development uses a hollow-shaft motor which does not require a reduction gear, and installs it coaxially with the steering column shaft, for a system configuration with superior mountability. The ECU is also a separate type that can be flexibly adapted to the installation location. In order to support 24 V power supply voltage and achieve degeneracy operation when the ECU or motor malfunctions, the ECU is designed to incorporate redundant functions.

4. System Configuration

4. 1 System Overview

The system configuration is shown in **Fig. 1**. The primary component parts are the ECU, electric actuator, and connected power/signal harness.

The coaxial steering actuator controls the steering based on commands from the ADAS ECU, and transmits torque output via the intermediate shaft[2] to the HPS.

The angle and torque information required for control is calculated from the values detected by the electric actuator motor and torque sensor.

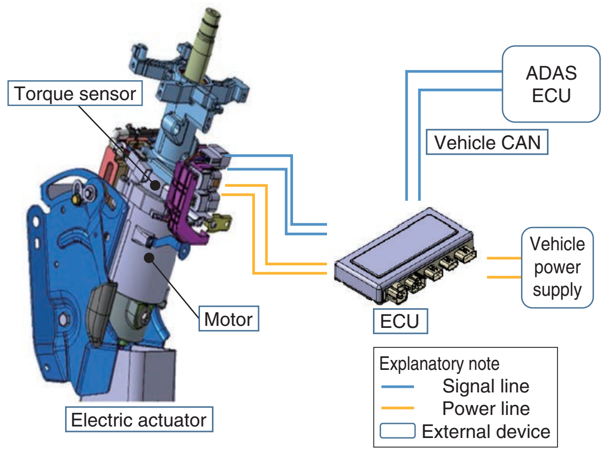

Fig. 1 System configuration

4. 2 ECU

The ECU system configuration is shown in **Fig. 2**. A new ECU supporting 24 V power supply voltage was developed for installation in a commercial vehicle. A redundant structure is used for the ECU microcontroller, motor driver, and CAN, dividing it into an independent system 1 and system 2. This enables normal system use and continued steering function when a malfunction occurs.

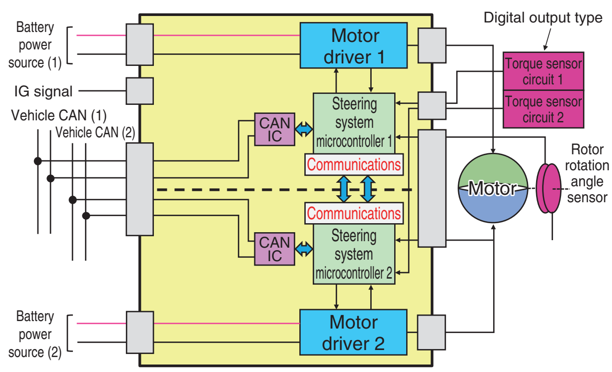

Fig. 2 ECU system configuration

4. 3 Electric Actuator

The system positions the hollow-shaft motor coaxially with the column shaft, and the torque sensor is incorporated in it. The motor has a redundant structure in the windings and rotation angle sensor, and in the same manner as the ECU is divided into an independent system 1 and system 2. The motor drives a single rotor using the magnetomotive force generated by each of the motor windings of both systems. While a conventional EPS uses a reduction gear to amplify motor torque, torque is output from the hollow-shaft motor, allowing improved mountability of the coaxial steering actuator. This results in a system with high response, low inertia, and high quietness.

The torque sensor is also redundant, and in addition to detecting driver torque, it is also used for purposes including steering feel control and hands-off detection.

5. Electric Actuator Control

5. 1 Control Outline

The control configuration is shown in **Fig. 3**. Control is composed of steering feel control, steering angle command control, and hands-off detection.

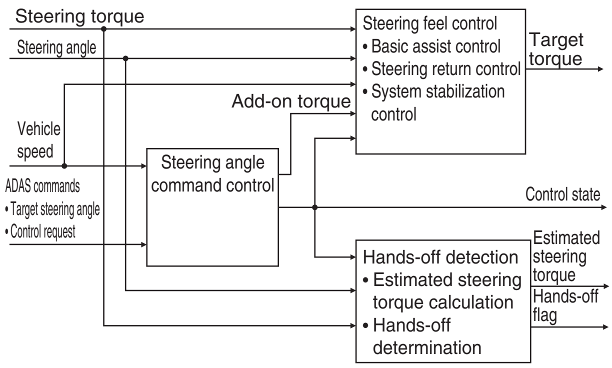

Fig. 3 Control configuration

5. 2 Steering Feel Control

Steering feel control is composed of basic assist control, steering return control, and system stabilization control. The output of the coaxial steering actuator is controlled using the total value of each control output and the steering angle command control output as the target torque.

Basic assist control performs assist based on the vehicle speed and driver steering torque in order to achieve both vehicle handling at low vehicle speeds and response at high vehicle speeds, which were previously difficult with HPS. Special assist is performed during steering angle command control to easily allow the driver to perform override steering.

Steering return control adds torque according to the difference between the target steering speed found from the steering angle and the actual steering speed in order to achieve smooth steering return.

For system stabilization control, the coaxial steering actuator is installed on the column shaft, and is connected to the HPS via the intermediate shaft. This reduces the vibration caused by the structure which has two torsion bars on the same axis, and improves control stability.

5. 3 Steering Angle Command Control

Steering angle command control calculates the torque required to track the actual steering angle by feedback calculation in response to the target steering angle received from the ADAS ECU, and outputs the result as add-on torque. It also judges control start and end according to the control request. Although the steering load changes depending on the HPS output, the electric actuator ensures stability regardless of the load condition and sets feedback gain that can provide sufficient response under the conditions of actual use.

5. 4 Hands-Off Detection

Hands-off detection is composed of estimated steering torque calculation and hands-off determination. Based on the steering torque, estimated steering torque calculation calculates the estimated steering torque that compensates for the torque deviation caused by inertia between the torque sensor and steering wheel, and also by viscosity and the difference between the rotational center and mass center.

Hands-off determination determines that the driver's hands are off the steering wheel and notifies the ADAS ECU when the estimated steering torque is at or below the threshold value for the designated length of time or more.

Figure 4 shows the coaxial steering actuator and a hydraulic RBS integrated actuator that has been commercialized by another company. In the coaxial steering actuator, the torque sensor is positioned directly below the steering wheel. However in the hydraulic RBS integrated actuator that installs the actuator directly on the HPS, the torque sensor and steering wheel are connected via the manual steering column and intermediate shaft. For this reason, the coaxial steering actuator is little affected by inertia and friction, and enables highly accurate estimation of steering torque, providing superior hands-off detection performance.

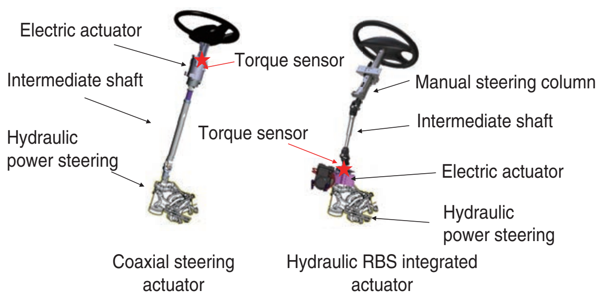

Fig. 4 Difference in torque sensor position

6. Conclusion

By installing a coaxial steering actuator on the column of a large-size commercial vehicle such as a truck or a bus, where the front axle load is large and changing HPS to EPS is difficult, we have created ADAS functions that utilize the HPS. The hardware was made redundant in order to improve safety and support future automated driving. Unlike C-EPS, because the structure of the coaxial steering actuator does not use a reduction gear, the steering actuator ensures high quietness and high response. In the future, we will expand sales of the coaxial steering actuator as an ADAS-supporting solution that can replace a manual steering column with minimal vehicle design modifications in commercial vehicles where the change to EPS is difficult.

References

1) K. SAKATA: Outlook for Steering System Technology Aimed at Self-Driving, JTEKT ENGINEERING JOURNAL, No. 1017E (2020) 9.
2) Y. KAWADA: Energy Saving Related Technologies Special Edition Development of Compact and Light-Weight Column Type Electric Power Steering, No. 1010E (2013) 40.



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