

Application of Electric Servo Brake System to Plug-In Hybrid Vehicle

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ABSTRACT

An electric servo brake system applied for use on electric vehicles was applied for use on plug-in hybrid vehicles in order to achieve fuel-savings together with good brake feel and enhanced operability for plug-in hybrid vehicles. The electric servo brake system is made up of highly accurate braking pressure control that functions cooperatively with regenerative brakes together with a structure in which pedal force is not influenced by braking pressure control. The configuration of these components enabled good braking feel even when the power train was being switched from one drive mode to another. Automated pressurization functions that are intended for plug-in hybrid vehicles and that operate with electric servo brake systems were also developed. These developed functions include stall cooperative control that functions cooperatively with the power train, regenerative coordinate adaptive cruise control, and hill-start assist. The application of these automated pressurization functions enabled the reduction of fuel consumption and enhancement of operability.

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INTRODUCTION

The growing demand for reduction in fuel consumption and CO₂ emissions with a view to protection of the global environment is accompanied by a rise in the attention being given every year to vehicles equipped with electric power trains, including electric vehicles (EV) and hybrid electric vehicles (HEV). These EVs and HEVs activate regenerative brakes when they decelerate, recovering kinetic energy in the form of regenerative electric power, and so are able to reduce fuel consumption. Various braking systems that enable regenerative coordinate braking that coordinate the distribution of regenerative braking force and friction braking force have been proposed for that purpose(1),(2),(3),(4),(5). One of these is the electric servo brake system(6). In order to decelerate according to the driver's intention when regenerative-friction brake coordination is in operation, the sum of the regenerative braking force and the friction braking force must always be matched to the demand from the driver (7),(8). In its application to the plug-in hybrid vehicle (PHEV) (9), the electric servo brake system has highly accurate brake pressure control that functions cooperatively with regenerative brakes, and this has enabled the system to provide deceleration characteristics that do not fluctuate regardless of the distribution of regenerative braking force and friction braking force.

On the other hand, when a vehicle stalls on a sloping road or other such location and the stalled condition continues while the vehicle drive motor outputs driving force, the electric power train will generate heat. Reducing the driving force in order to prevent overheating results in the vehicle rolling back down the slope. Also, during deceleration when adaptive cruise control is in operation, there are cases when energy loss occurs due to the application of friction braking. That is to say, there is latitude for enhancement of operability and reduction of fuel consumption. Therefore a stall cooperative control that operates with the electric servo brake system to prevent overheating and rolling back down a slope during a stalled condition was developed, together with regenerative adaptive cruise control and hill-start assist, and applied to the PHEV.

This paper describes these technical elements involved in the electric servo brake system control that has been applied in the PHEV.

SYSTEM OVERVIEW

The electric servo brake system is shown in Figure 1. This system is made up of a pedal feel simulator and pedal stroke sensor in a pedal operating unit, a tandem motor cylinder in a braking pressure generating unit, and an electronic control unit (ECU). The pedal feel simulator generates the pedal

stroke and force when the pedal is operated. The tandem motor cylinder generates the brake pressure instructed by the ECU according to the amount of pedal operation detected by the pedal stroke sensor.

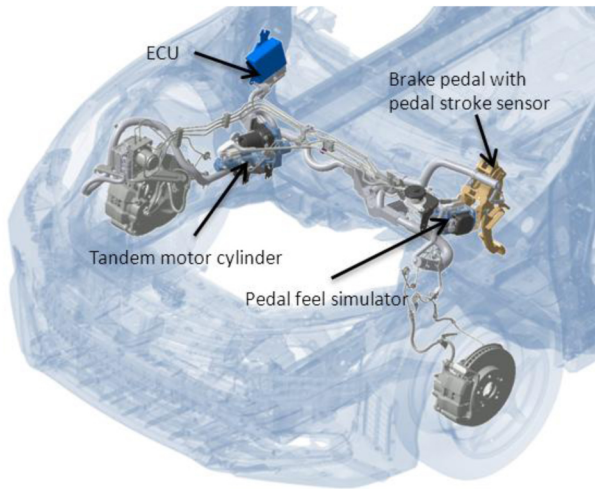


Figure 1. Overview of electric servo brake system

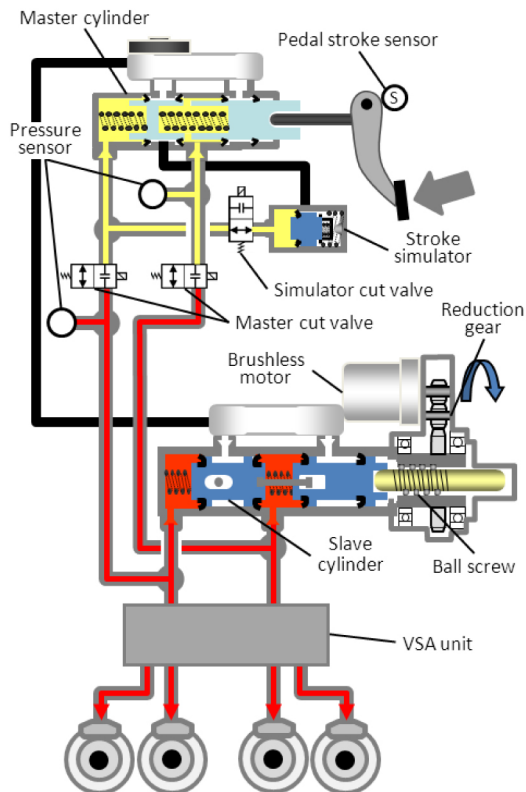


Figure 2. Configuration diagram of electric servo brake system

Figure 2 shows the operation of the electric servo brake system when brake pressure is generated. When the pedal is operated, the ECU determines the brake pressure target value based on the amount of pedal operation. The brushless motor

is then operated by the brake pressure control and at the same time the master cut valve is closed. This generates brake pressure downstream from the slave cylinder. The brake pressure is transmitted to the wheel cylinders through the vehicle stability assist (VSA) unit. When the various cooperative control functions demand the braking force, control is implemented using the brake pressure demanded by the cooperative control functions as the target value for control, and this enables generation of braking force.

Figure 3 shows a block diagram of plug-in hybrid system. Communication between the electric servo brake system and power train takes place through the controller area network (CAN) bus. Table 1 shows operation modes of the plug-in hybrid system. This power train configuration combines the high-voltage battery and engine with the motor and generator, and this enables the three operating modes of EV Drive, Hybrid Drive and Engine Drive.

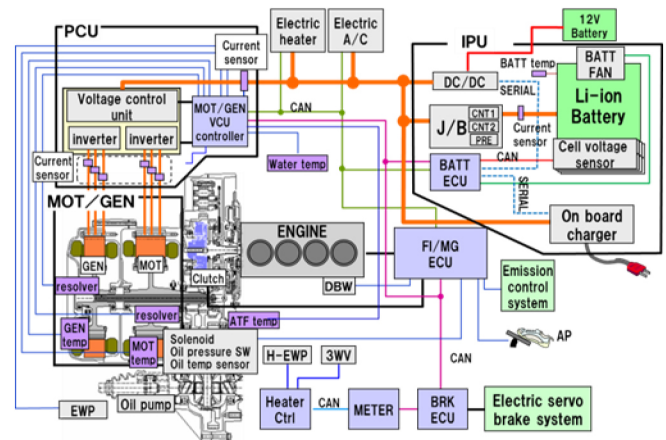


Figure 3. Block diagram of plug-in hybrid system

Table 1. Operation modes of plug-in hybrid system

			— Electrical Transfer — Mechanical Transfer
EV Drive	Hybrid Drive	Engine Drive	
Use electric energy from battery to drive motor	Use electric energy from engine generator to drive motor, with assistance from battery	Use engine to directly drive wheels	

BRAKING FEEL DURING REGENERATIVE COORDINATION

As described above, the regenerative coordination function performs coordinated distribution of regenerative braking force and friction braking force to generate the braking force required by the driver. The upper limit of the regenerative braking force varies from moment to moment according to such factors as the powertrain operation modes