

Main Design Factors and Unified Software Structure for Cable Puller and Caliper Integrated Type Electric Parking Brakes

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ABSTRACT

The main classification of Electric Parking Brakes (EPB) can be made into cable puller and caliper integrated types. In this paper, the main design considerations that need to be made for each type of system will be examined. In terms of mechanical design, actuator design factors including target capacity, system size, and vehicle mounting will be briefly discussed. In terms of software, a unified software structure that can incorporate both types of EPBs will be introduced. This unified approach, made up of fixed and variable modules, allows for more efficient software development for both types of EPB systems. The fixed modules are related to the identical target functions regardless of EPB type, while the variable modules are made up of the different considerations that need to be made depending on the EPB type in order to meet such targets. Finally, some test results of target functions for both types of EPB systems will be given.

INTRODUCTION

The application of Electric Parking Brakes (EPB) in automobiles has steadily increased through the years due to benefits of improved interior design and enhanced safety and comfort features [1]. The main classification of Electric Parking Brakes (EPB) can be made into cable puller and caliper integrated types as shown in Fig. 1. In cable puller type systems only the hand lever or parking brake pedal is replaced with an EPB actuator, while in caliper integrated systems independent actuators are added on to each rear caliper.

The main benefit of cable puller type systems is that the parking brake itself (drum brake, drum-in-hat, or parking

integrated caliper) does not need to be changed and can be carried over from previous conventional parking brake applications. However, the parking cable remains a key design factor and much effort needs to be made to find proper actuator mounting locations and cable routes. On the other hand, caliper integrated type systems have the advantage that all parking cables are eliminated. However, as the EPB actuator is located directly on the rear caliper, an added difficulty in development occurs in which the parking brake and normal brake design and validation phases must be carried out concurrently. As such, the selection of a preferable type of system is usually based on the particular priorities of the car manufacturer.

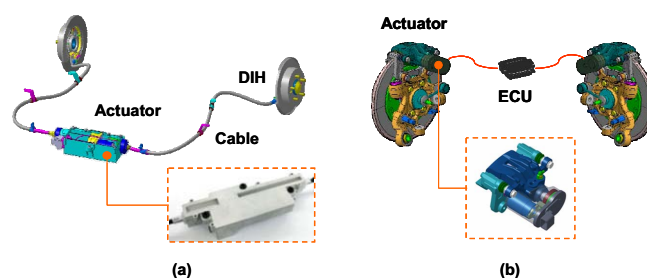


Fig. 1 (a) Cable puller and (b) caliper integrated EPB systems.

In this paper, the main design considerations that need to be made for each type of system will be examined. In terms of mechanical design, actuator design factors including target capacity and vehicle mounting will be discussed. Test results regarding functional, durability, and noise performance will be presented.

Although the resulting vehicle functionalities are identical for both systems, the control considerations vary depending on the different mechanical structural build up

of each system. With this in mind, a unified software structure that can incorporate the differences of both types of EPBs will be introduced. This unified structure is made up of fixed and variable modules. The fixed modules are related to the identical target functions such as static apply, static release, and dynamic braking. On the other hand, the variable modules are made up of the different considerations that need to be made depending on the EPB type in order to meet the performance targets of such functions. This type of unified approach was developed with the purpose of improving the efficiency of the software development process.

After description of such shared performance target indices and different control design considerations, a brief discussion of motor duty ratio control and the different feedback control loops, namely, force feedback and current feedback that are used respectively for the cable and caliper type EPBs will be made. Finally, some test results for both types of EPB systems will be given.

ACTUATOR DESIGN

The basic composition of the actuator for both the cable puller and caliper integrated EPBs is made up of the motor, gear box, and screw as shown in Fig. 2. The only difference is that the screw in the cable type actuator will act to pull the parking cable to activate the DIH (drum-in-hat) parking brake while the screw in the caliper type actuator will push the caliper piston directly against the friction pad.

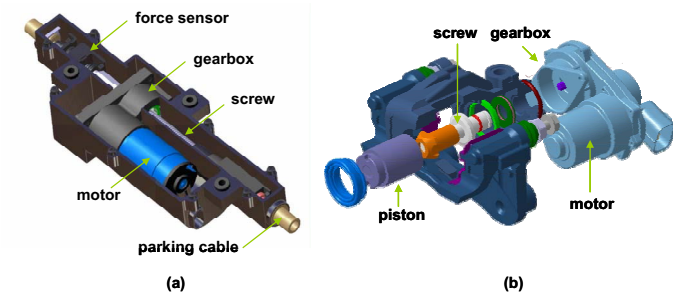


Fig. 2 (a) Cable puller and (b) caliper integrated EPB actuators.

As such, the basic principal of the mechanical design for both types of actuators is the same as outlined in Fig. 3. The design process begins with the system design phase which includes the calculation of parking brake force and actuator force target values. More specifically, the required parking force for a given vehicle at a specified hill slope angle is determined and from this the force that needs to be generated by the EPB actuator is calculated [2]. Different design factors must be considered depending on the type of EPB in this calculation. Namely, factors such as the cable efficiency, cable routing and DIH brake properties must be considered for the cable puller EPB, while the effective disc radius and friction pad properties must be considered for the caliper integrated EPB.

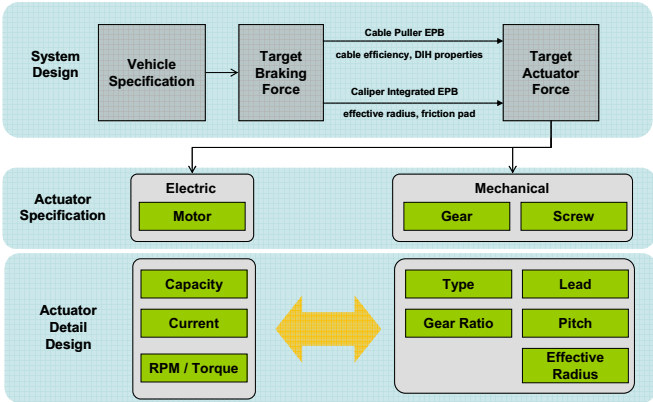


Fig. 3 Outline of mechanical design procedure.

Once the appropriate actuator force targets have been set for either type of EPB actuator, the next step is to set the specification of parts for the actuator, which basically includes the capacities of the motor, gears, and screw. Then, in the detail design phase the motor current, speed, and torque, gear type and ratio, and screw lead and pitch are designed [3]. In this stage it is important that these three sub-components are designed concurrently to satisfy various EPB system requirements at once. Apart from the target actuator force, the actuator must also meet the system response time and durability requirements. For this, it is important that the actuator is designed to make the most efficient use of the motor.

Table 1 Basic test results for cable puller EPB.

Test	Results	
Actuator Force (Current)	120 kgf (15A)	
Response Time	Apply : 1.0 s Release : 0.8 s	
Noise (driver seat)	42 dB	
Durability	150,000 cycles	

Table 1 shows the results from basic tests that are carried out to check that developed samples meet requirements. This table shows results of actuator force, current consumption, system response time, activation noise, and durability for the cable puller type EPB. Normally, the durability requirement for EPBs is 100,000 cycles at peak in-use actuator force due to various extra functions other than basic parking that can be required

of the EPB system. Extra functions such as auto hold and drive away release will be later described in Table 2. In the durability test of Table 1, the actuator force was set at 120 kgf and the test was conducted until failure of the system, which resulted in 150,000 cycles.

Another obvious but important requirement for the actuator is its size. From a vehicle mounting standpoint, not much space is allotted in the vehicle for EPB installations. In general, cable puller EPBs are mounted on the underbody of the vehicle as shown in Fig. 4 and it has been found that the thickness of the actuator has the greatest influence in determining its mounting capability. For caliper integrated EPBs, the actuator must be designed together with the caliper to make sure that it fits in the rear wheel. Also, due to the added volume of the actuator compared to conventional calipers, the bump conditions of the suspension system must be considered as shown in Fig. 5 to make sure that no interference between the EPB actuator and suspension system occurs at any time.



Fig. 4 Installation examples of cable puller EPBs.

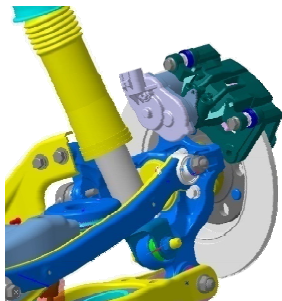


Fig. 5 Bumping consideration (maximum bump condition) for caliper EPB installation.

SOFTWARE DESIGN

EPB FUNCTIONS

The previous section outlines a general description of the EPB design procedure, in which the design process begins with recognition of vehicle specifications. However, in common practice the EPB actuator is not designed separately for each target vehicle. Usually, due to the different capacity DIH brakes or rear disc effective radii used according to the vehicle requirements, a single model of cable puller or caliper integrated EPB, respectively, can be used for a wide range of vehicles. It is the software tuning that is usually changed for each vehicle development project.

Before discussing the different control design factors that must be considered for each type of EPB, it can be useful to first look through the various functions of EPBs. Table 2 gives a brief description of the common EPB functions, in which the most basic functions are static apply, static release, and dynamic braking. These three functions form the basis for all of the other complementary functions which are usually optional depending on the car maker strategy.

Although the resulting functions provided to the end user are the same regardless of the type of EPBs, the software structure and algorithm are different. The next section will provide a description of the differences based on analysis of the make-up of the three aforementioned basic functions.

Table 2 Description of EPB functions.

Function	Description
Static Apply	EPB application by switch
Static Release	EPB release by switch
Dynamic Braking	Emergency braking with EPB in case of service brake failure or brake pedal blockage
Auto Hold	Automatic application of EPB
Drive Away Release	Automatic release of EPB
High Temp. Re-Clamp	Re-clamping of EPB at high temperatures
Adaptive Clamping	Application of adaptive clamping according to hill slope angle
Key Out Apply	Automatic application with ignition off
Release Inhibit	Inhibition of EPB release depending on circumstances (eg. brake pedal off)

SOFTWARE STRUCTURE

Since the aforementioned resulting functions are the same for either the cable puller and caliper integrated EPBs, it is possible to maintain a similar structure of software for both types of EPB. In particular, if both types of EPBs need to be developed, it can be beneficial to base the software development on a unified approach to increase efficiency. As such, a unified software structure for EPB coding has been developed in the current study.

Fig. 6 shows the developed software structure which incorporates both types of EPBs. It is built up of fixed and variable modules. Fixed modules are modules which need to be coded just once, while the variable modules need to be adjusted for the target vehicle or application accordingly. As shown the input commands such as vehicle, switch, and EPB status which define the input and the function output such as static apply, static