

Electro-Mechanical Brake for Front Wheel with Back-Up Braking

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ABSTRACT

Electro-Mechanical Brake (EMB) is the brake system that is actuated by electrical energy and has a similar design with the Electric Parking Brake (EPB). It uses motor power and gears to provide the necessary torque and a screw & nut mechanism is used to convert the rotational movement into a translational one. The main difference of EMB compared with EPB is that the functional requirements of components are much higher to provide the necessary performance for service braking such as response time. Such highly responsive and independent brake actuators at each wheel lead to enhanced controllability which should result in not only better basic braking performance, but also improvements in various active braking functions such as integrated chassis control, driver assistance systems, or cooperative regenerative braking. Although the EMB system has the potential for numerous advantages and innovations in braking, it has yet to be successfully introduced in series production mainly due to safety and cost concerns. Recent studies have been made to investigate the functional safety aspects[1] and additional mechanical backup measures[2] in this regard.

Although the EMB is conventionally thought of as a solution for oil-free braking system[3-4], the EMB system introduced in the current paper includes a hydraulic piston to make several functions possible. First, the hydraulic system allows for a mechanical back-up mechanism that leads to increased reliability. Second, the clamping force for braking control can be measured with a pressure sensor. And finally, the dual piston structure proposed in the current paper, which leads to amplification of the force transmission, allows for the design of lower specification and higher cost effective motor and gear components.

This new concept of EMB is termed the hEMB (hybrid EMB) in this paper. This study proposes to use a combined system of front hEMB and rear hydraulic caliper. This type of system has the potential of providing many advanced braking functions without the high cost associated with fully electric four wheel brake by wire systems. Prototypes of hEMB actuators were made and attached in a test vehicle. Results of bench and vehicle tests will be given to show the functionality of the system.

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INTRODUCTION

A recent issue in the brake industry is the increasing desire to have affordable vacuum-free braking. In conventional braking systems the vacuum of a vacuum booster is usually generated by the vehicle engine manifold, which decreases the fuel efficiency of the vehicle. For turbo charge engines that improve fuel efficiency, the amount of vacuum from the engine is insufficient to effectively use the vacuum booster, so an electric vacuum pump is additionally used with extra cost. In the first

case, a vacuum-free braking system will lead to more fuel efficient use of the engine and in the second case the cost of an electric vacuum pump can be negated. Another growing requirement for today's brakes is the increased capability of active braking for application to cooperative regenerative braking and driver assistance systems such as adaptive cruise control or autonomous emergency braking. A brake by wire (BBW) system is a representative system that can satisfy both of these trends at once.

The fully electric BBW system[5] is generally composed of Electro-Mechanical Brakes (EMB) at each wheel and a pedal simulator that processes the driver's braking intention. In general, EMB systems with highly-responsive and active independent control of the brake actuators at each wheel can lead to great dynamic control flexibility and improved brake performance. Furthermore, integration with other chassis-control-systems, cooperative regenerative braking, and various driver assistance functions is simple due to such inherent properties. However, EMB systems have yet to be successfully introduced in series production mainly due to the underlying perception of the lack of reliability of electronic components and overall cost concerns. Recent studies have been made to investigate the functional safety aspects and additional mechanical backup measures in this regard. This paper is a further investigation in this context that has potential of greatly improving the cost effectiveness of the system.

A new EMB concept, the hEMB (hybrid EMB) is introduced in this paper. The hEMB is characterized by a dual piston structure linked by hydraulics inside of the caliper. The different cross-sectional areas of the two pistons lead to mechanically simple amplification of the braking force transmission. This amplification allows for the use of reduced size motors and gears compared to ones that would have to be used for normal fully electric EMBs. Also, the hydraulics in the hEMB actuator can be used to provide a highly effective and simple mechanical backup system. Another benefit of using hydraulics is the possibility of using a pressure sensor to measure the clamping force for feedback brake control. Compared to other alternatives of measuring clamping force, the pressure sensor is a proven type of sensor with relatively high reliability.

In terms of vehicle level, this study proposes a combined system with front hEMB and rear conventional hydraulic calipers. Such system configuration maintains many functional benefits of a brake by wire system that comes from highly responsive active brakes. Also, the conventional hydraulic rear brakes do not require a vacuum booster so this brake configuration is a vacuum-free system. More importantly, this vehicle configuration can have great cost benefits compared to fully electric brake by wire systems since EMBs are not used on the rear axle and the number of required electric control units (ECU) is greatly reduced.

CONCEPT OF THE HYBRID EMB AND THE VEHICLE APPLIED HEMB

Dual Cylinder Structure

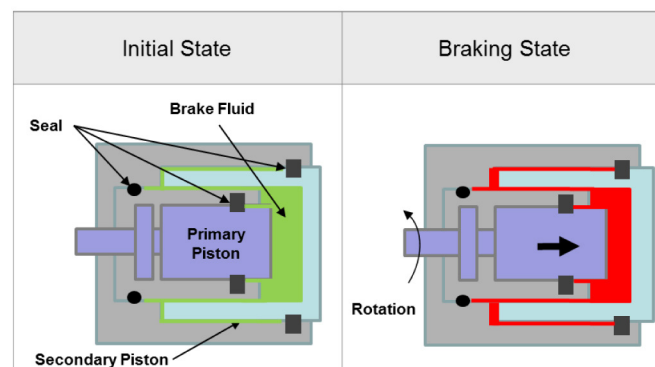
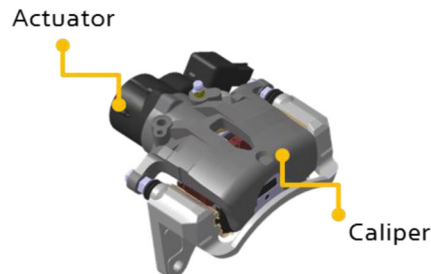


Figure 1. The hEMB mechanism

As mentioned, the main characteristic mechanism of the hEMB caliper is its dual piston cylinder structure with hydraulics. As shown in Figure 1, the primary piston is the one linked directly to the motor and gear actuator through a screw & nut mechanism. When the primary piston is activated, hydraulic pressure is built up between the primary piston and the secondary piston, which is the piston that is actually in touch with the brake pads. This pressure build up acts to generate braking force via the secondary piston just as in conventional hydraulic calipers. The ratio of different cross-sectional areas of the two pistons gives the additional amplification of force transmission that leads to reduced motor and gear specifications. Because generally low torque and high speed motor is smaller than high torque and low speed motor. So the optimized size of the hEMB caliper can be designed as shown in Figure 2. Compared to conventional hydraulic calipers, there is minimal difference in the height and width dimensions and only the length is increased by 55mm. And as mentioned, a pressure sensor can be used to measure the pressure build up between the pistons that can be converted to clamping force for control purposes.