Design and Implementation of a Fault Diagnosis and Fail Safe on an Electronic Parking Systems

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***Abstract*—This paper is intended to present the design and implementation of a fault diagnostic and fail safe for an electronic parking brake system. The fault diagnostic function includes an input signal, output signal, and fault diagnostic using a microprocessor. The fault diagnostic function determines faults in the main microprocessor. The EPB has the function of the microprocessor and the permissible range of system control. The input signal detects faults using the voltage of the switch pole, the output signal defines faults using the current level of the motor. The microprocessor judges failure using internal software. And a sub microprocessor monitors the status of the main microprocessor using periodic communication between the main microprocessor and the sub microprocessor. Also, the microprocessor controls the output signal when emergencies occur. When the sub microprocessor judges that the main microprocessor and the system recovers from the fault. The safety and reliability of the EPB system can be improved using the proposed fault diagnosis system.**

***Index Terms*—EPB (Electronic Parking Brake), fail-safe, diagnostic, safety, reliability**

I. Introduction

The EPB (Electronic Parking Brake) system is a device used to park a car that operates the brake caliper electronically. The number of cars implementing EPB is growing in the automotive market because EPB provides comfort and safety to drivers. Also, electronic systems in automotive parts are actively being applied because microprocessor performance has been improved and the price of motors has dropped. In particular, parking brakes, which are engaged by hand in high level vehicles, are being replaced with electronic parking brakes [1]–[3]. However, electronic systems substitute electronic signals and motors for mechanical parts [4]. So, such systems are subject to malfunction due to noise, faults of sensors, errors of the microprocessor, aging, and failure of the motor or EMC (Electromagnetic compatibility). EPB system which can be subject to errors of electric devices, can affect the parking performance of cars [5]. Of course it requires proper operation when it is in failure. So this paper recommends that the EPB system be designed and implemented to include a self-diagnostic function and a fail-safe function, in order to provide reliability and stability that can prohibit the failure and breakage of the EPB system [6].

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II. Structure of EPB System

The EPB system can detect the requirements of drivers using a switch signal and can work the brake by operating the left and right motors. Also, the EPB system performs a self-diagnostic function and detects the brake status by measuring the motor current and the status of the switch. Fig. 1 is a schematic block diagram of the EPB system structure.

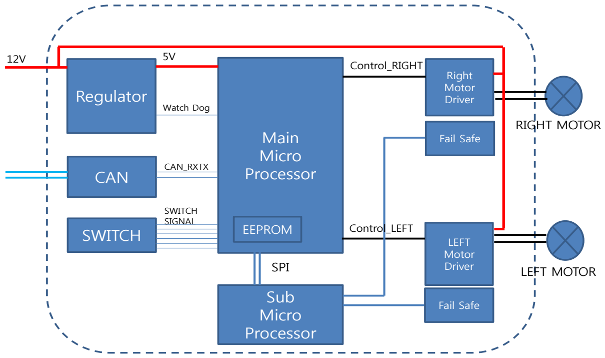

Figure 1. Block diagram of EPB system

The EPB system consists of an input part for the detecting of the switch signal, a motor part for the operating of the brake, and a control part to decide if the driver IC should be engaged or not. Power to run the DC motor is controlled by the microprocessor. The EPB system uses EEPROM to save internal variables and CAN to communicate with other modules. SPI communication connects the main microprocessor and the sub microprocessor. The sub microprocessor always monitors the main microprocessor and is designed to reset the main microprocessor when failure occurs. The EPB system has a scheduler module, a signal processing module, a control module, a self-diagnostic module, a central processing module, a fail-safe module, and a communication module. Fig. 2 shows the structure of the software. The data processed by the signal processing module is transferred to a control module and a self-diagnostic module. The self-diagnostic module decides the status of EPB using the processing data. A central processing module controls the output signals depending on the status of the self-diagnostic module and saves the current status in EEPROM. The communication module communicates with other modules and the scheduler module controls the operation of the EPB system.

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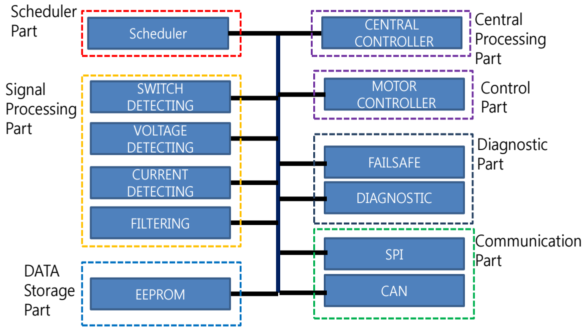

Figure 2. Software structure of EPB system

III. Structure of EPB System

The self-diagnostic function of the EPB system has 3 steps, which consist of a self-diagnostic of input signals (switch and voltage), a motor signal (current), and a microprocessor. This paper recommends that the EPB system be robust in the detecting of the failure of the microprocessor status, the status of the output signal, and the validity of the input signal.

A. Design for Self-Diagnostic

1) Self-diagnostic of input signal

The EPB system performs filtering of the switch signal by considering the noise and sudden signal variants. Fig. 3 provides a block diagram of the switch signals.

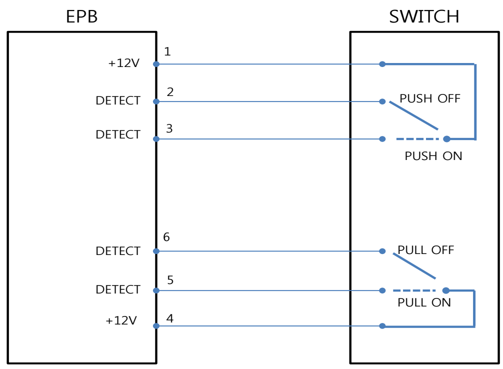

Figure 3. Block diagram of switch signal

The switch signal is determined to be a valid signal when the same signal is detected five times after reading the status of the switch signal every 10ms. The state of the switch signal is determined through a combination of signals after detecting a valid signal. Table I shows the self-diagnostic function depending on the state of switch signal.

TABLE I. Self-Diagnostic Function as Switch Status

Number	1	2	3	4	5	6
PUSH OFF	H	H	L	H	H	H
PUSH ON	H	L	H	H	H	H
PULL OFF	H	H	H	H	L	H
PULL ON	H	H	H	H	H	L
FAULT	unexpected signal					

The EPB system uses the A/D module to detect the voltage level in order to define its own operating state. Also, the normal voltage range is defined by considering the hysteresis. Fig. 4 shows the operating range of voltage.

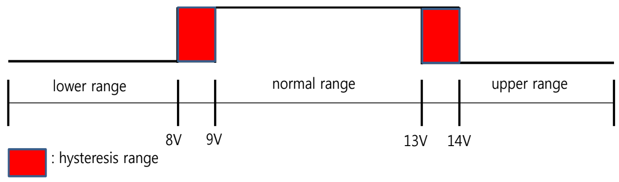

Figure 4. Operating voltage range of EPB

2) Self-diagnostic of motor control

The self-diagnostic system of the motor acts to protect the motor against system damage. System damage can occur because of motor malfunction and decreasing of the control performance; these faults can be due to aging or motor fault. The self-diagnostic system of the motor implements the characteristic curve through current sensing and detects failure of the motor by comparing the value of the real current and the value of the characteristic curve. It detects performance faults and failures of the motor by considering the stability and the transient. In this paper, the transient state defines the times to start and stop the motor. The stability defines the times in which the motor operates normally. Fig. 5 shows the current character curve of the stability and the transient.

Figure 5. Current characteristics curve

The character curve of the motor current needs to be periodically updated according to the learning algorithm, because brake caliper variation alters the character curve when the EPB system is used for a long time. There is the possibility of misjudgment because, owing to algorithm failure or the insertion of an obstacle, the EPB system can regard abnormal current caused by system aging as a failure of motor-operation.

3) Self-diagnostic of microprocessor

The self-diagnostic of the microprocessor checks whether the software module is operating on schedule or not. Also, it determines whether to perform the current software module after checking the operation of the prior software module. Fig. 6 provides a block diagram of the self-diagnostic of the microprocessor. In this figure, module 2 checks whether module 1 is in operation or not. If module 1 is completed, module 2 is operated. If it is not completed, the microprocessor recognizes an error and then module 3 is operated.

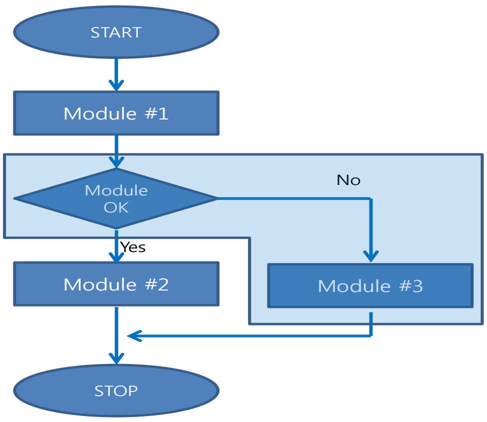

Figure 6. Block diagram of process diagnostic function

B. *Solution of Self-Diagnostic*

The EPB system has a control performance system that uses a self-diagnostic to protect the system against errors. So, the system has a good level of reliability. Four kinds of measures for the self-diagnostic are designed, taking into account the severity of the error and the effects on the system. Table II shows the types of state and actions according to detected errors.

TABLE II. TYPE OF STATUS AND ACTION ACCORDING TO DETECTED ERROR

Type	STATUS	ACTION
Switch reaction	PENDING HISTORY	Release brake : Vehicle speed > Ref speed Park brake : Vehicle speed < Ref speed
Voltage reaction	PENDING HISTORY	Stop motor : Over and under voltage
Current reaction	PENDING HISTORY	Stop motor : Over current
Reset reaction	PENDING HISTORY	Self detection: active low of reset line Logic error: watchdog signal is removed.

Switch reaction is operated when a switch is at fault or the EPB is at fault because of an error of the switch signal. The switch reaction has 2 states; these are PENDING and HISTORY. PENDING is the status generated when errors occur. HISTORY is the status that is generated when an error occurs and is removed. When the EPB system detects that the status of a switch is PENDING, the EPB parks or releases the brake of the vehicle according to the vehicle speed. Also, EPB should not operate repeatedly until any PENDING status is removed.

Voltage reaction detects failures of the operating voltage, which can be higher or lower than the reference voltage. If the voltage is higher or lower, EPB indicates failure and disconnects the power to the motor. The voltage reaction has 2 statuses, PENDING and HISTORY. PENDING is the status generated when errors occur. HISTORY is the status that is generated when an error occurs and is removed. When operating voltage rises above a set value, EPB cannot operate motors due to breakage of the motor driver. When operating voltage is below the set value, EPB cannot operate motors due to low voltage. So, the EPB system can operate within the reference defined. Also, the EPB system secures proper hysteresis by considering the voltage drop, which is caused by cranking and battery problems.

EPB indicates failure when the system registers over a set value of current. And, the current reaction stops the operation of the motor. The current reaction has 2 statuses: PENDING and HISTORY. PENDING is the status generated when errors occur. HISTORY is the status that is generated when an error occurs and is removed. The driver IC of the motor stops the operation of the motor driver to protect against damage due to overcurrent.

A reset reaction operates when a failure of software occurs. A watchdog signal is not supplied normally to the regulator IC. The regulator IC generates a low level of the reset line. So, a reset of the microprocessor occurs by force. Also, EPB causes a forcible reset of the microprocessor when the microprocessor does not operate normally due to an error of logic or PC (Program Counter).

IV. DESIGN FOR FAIL-SAFE

The EPB system has provided various solutions and can find many kinds of errors due to the self-diagnostic function. However, the self-diagnostic function does not operate normally when the main microprocessor operates abnormally. So, the sub microprocessor checks the main microprocessor status using SPI communication to prepare for the failure of the microprocessor. Table III shows the definition of the protocol between the main microprocessor and the sub microprocessor.

TABLE III. PROTOCOL BETWEEN MAIN AND SUB MICROPROCESSOR

Byte	Description
Byte #1	Switch information
Byte #2	High 4 bit : LEFT motor information Low 4 bit : RIGHT motor information 0b0000 : STOP 0b0001 : PARKED 0b0010 : PARKING 0b0100 : RELEASED 0b1000 : RELEASING
Byte #3	Count

The sub microprocessor detects the signal of the switch and the current of the motor. It can reset the main microprocessor and stop the operation of the motor. In this paper, 2 types of fail-safe controls are defined.

The switch failure function defines the failure of the main microprocessor when the real value of the switch and the receiving value of the switch from the main microprocessor are different. So, the reset of the main microprocessor occurs due to the sub microprocessor. At this time, the operation of the main microprocessor is complete. Also, the sub microprocessor defines failure of the main microprocessor when the main microprocessor cannot detect the current of the motor. So, the reset of the main microprocessor occurs due to the sub microprocessor.

V. Implementation and Verification of Diagnostic Function

The EPB system consists of a control board for the EPB, a PC to monitor CAN, a wire interface, and the structure of the brake, as shown Fig. 7.

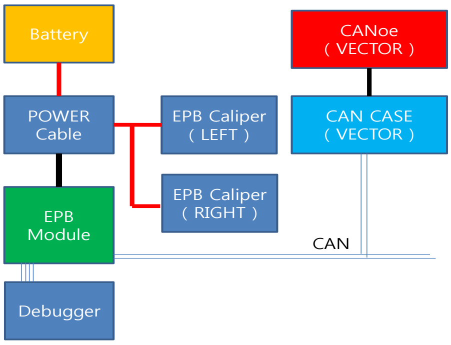

Figure 7. EPB system with a CAN monitoring tool

The EPB software operates using the scheduler module. It uses CAN to control the EPB system and to detect failure. Fig. 8 shows the operation of the motor when the status of the switch is failure. It releases the parking brake when the vehicle speed is over a set value in the switch reaction status. It clamps the brake when the vehicle speed is under the set value in the switch reaction status.

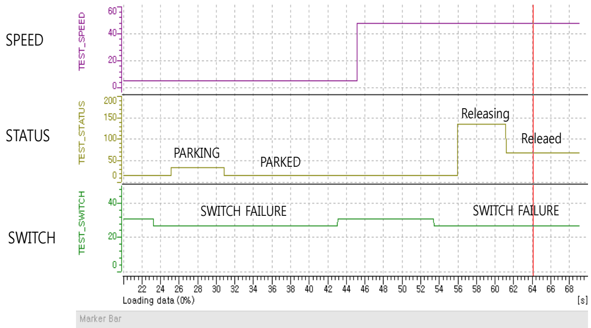

Figure 8. EPB motor operation in switch reaction status

Table IV provides verification of the voltage reaction and shows the operation of the EPB system the in normal voltage range.

TABLE IV. EPB Operation Base on the Voltage

Voltage	SWITCH	ACTION
7V	PARK / RELEASE	NO ACTION
12V	PARK / RELEASE	ACTION
16V	PARK / RELEASE	NO ACTION

Fig. 9 is presented to verify the current reaction. IT shows the stop operation of the motor when the EPB system detects over current due to heavy load.

Figure 9. EBP motor operation in over current of EPB

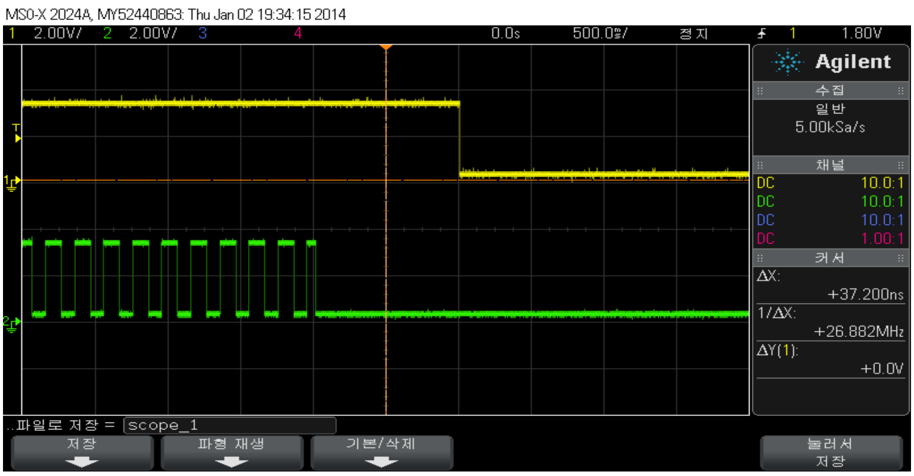

Figure 10. The reset operation during no watchdog signal

Fig. 10 shows that the regulator makes the reset operation of the microprocessor when the watchdog signal is removed forcibly.

Fig. 11 shows the method of verifying the operation to check switch failure. It shows that the sub microprocessor causes main the microprocessor to reset when the signal is changed forcibly.

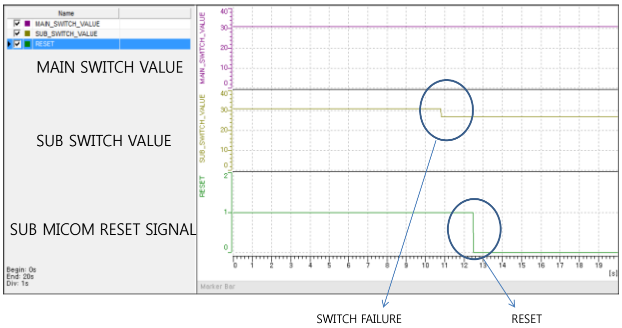

Figure 11. EPB operation when EPB is the switch failure

Fig. 12 shows the operation of current failure when the load of the motor is applied and the current signal to the main microprocessor disconnects. While the main microprocessor applies the load to the motor, the sub microprocessor cuts off the current of the motor to stop it. After turning off the motor driver, the sub microprocessor causes the microprocessor to reset when it detects current of over the set current value.

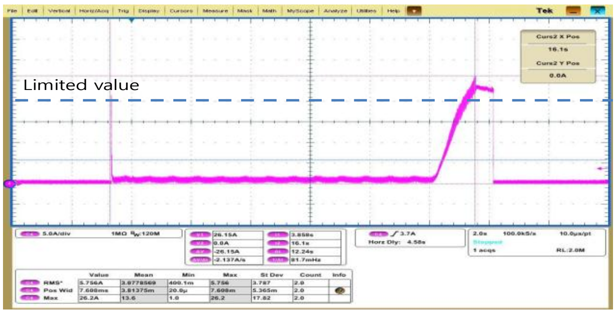

Figure 12. EPB operation when EPB indicates current failure

VI. Conclusion

In this paper, self-diagnostic and fail-safe functions are designed and implemented to protect an EPB system and to confer better reliability to that system. The solution of the EPB diagnostic defines the switch reaction, the voltage reaction, the current reaction, and the reset reaction. And, it is able to operate normally when the EPB system detects its own failure. Also, the solution of the EPB fail-safe defines switch failure and current failure. This system can be operated normally when the EPB system detects its own failure.

Implementation of the self-diagnostic and the fail safe function can allow us to not only detect errors of the EPB system but also errors of the control unit. The EPB system can attain stability even if failures occur because the EPB system has the solution of its own failure.

Acknowledgments

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