Design and Implementation of EMB System

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***Abstract*—The EMB(Electric Mechanical Brake) system is replacing the former hydrodynamic brake system. A brake system is a nonlinear system which applies a different compressive force depending on the position of the brake pad. The EMB system operates the brake by the motor instead of the hydrodynamic system. So the new design of brake caliper and the development of the motor controller and the invertor are needed. The gap between the pads shall be controlled exactly to operate an accurate force control. The new algorithm to compensate the pad abrasion and the disk abrasion is needed. In this paper, the mechanical part are designed to operate the brake and the EMB controller are designed and implemented with a motor controller and an inverter. The EMB controller model is verified by the MATLAB. The initialization algorithm is developed to compensate the pad abrasion and the backlash of the gear to make the same gap between the disk and the pad. The suggested algorithm detects the pad gap equally and the force depending on the pad gap is measured consistently.**

***IndexTerms*—EMB, Vector control, PI control, Interpolation, Caliper**

I. Introduction

The replacements of hydrodynamic systems are being developed to solve the environmental problems in a car. More electrical components in vehicle are also being developed to solve the environmental problems. And the safety in car is more emphasized. TheEMB system is replacing the traditional hydrodynamic brake system. This will increases fuel efficiency and mitigate the aforementioned environment problem by removing the oil, pipelines and pumps which are related to the former system. The new system has been installed in a prototype vehicle thus far because certain safety issues remain. Owing to these issues, the change from the hydrodynamic system to the electric system has been challenging. The EMB system is a nonlinear system which applies different.

Compressive force depending on the position of the brake pad. The EMB system operates that the brake caliper is operated by the motor, the brake caliper pushes the brake pad, and the brake pad makes the vehicle stop. A hydrodynamic brake system can operate the brake caliper using sufficient force due to the high oil pressure. However, the EMB system cannot measure the force of the brake caliper directly.The difference of the force in caliper are occurred because of the initial pad position, the status of the pad abrasion. So the new algorithm to assume gaps between the brake pad and the disk is needed. In this paper, the mechanical part and the controller of the EMB are designed and implemented.

II. Related Work

The development of the EMB system is needed as expansion of the hybrid car and electric vehicle. The EMB model has been studied in many papers and the prototype of the EMB are being developed. In [1], the gap control algorithm has been developed using the EMB model. That system consists of a DC Motor, a reducer, and a screw. The modeling of the reducer and the screw are developed using LuGre's Friction model. The disk brake system are approximated as the spring damper. The gap control algorithm is made using the torque variation and the position variation. In [2-3], the sensor fault model of the EMB system are suggested, fault diagnosis is operated using the current, force and position. The residual models of the current, force and position are studied, the fault diagnosis are tested after injecting the error signal. In [4], the compensation method of the gear backlash has been studied.

The current control is used when the EMB applies and the position control is used when the EMB releases. The cascading speed controller are added to remove the discontinuity of the control. In [5], the EMB model is made by the experiment. The operating time of the EMB is the same in any position because the PI gains are changed depending on the pad position. In [6], the EMB model is designed using MATLAB(tool), it is validated by the test bench. The DC motor is designed considering of the magnetic field. The reducer is designed using the single pinon planetary gear. The caliper parts are designed as the spring damper. Not onlymany papersare studied about the simulation and the modeling but also there is less the real design and implementation about the EMB.

III. EMB System

There is the EMB system consisting of the sensor parts, the control parts of the motor, the brake caliper parts of the EMB, the gear parts to operate the brake caliper. A block diagram of the EMB system is presented in Figure 1. The force is amplified as the motor runs and the brake caliper is operated by the amplified force. The brake system is operated by the brake caliper with the inner pad and outer pad.

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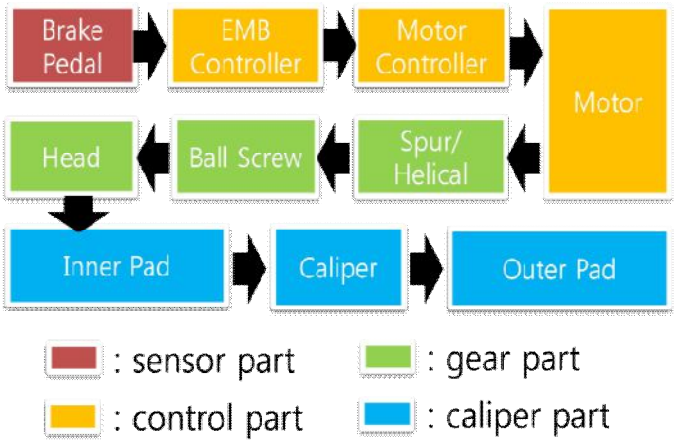


Fig.1. A block diagram of the EMB system

A. Mechanical Part

A mechanical parts of the EMB system are presented in Figure 2. Those consist of the motor, the spur and helical gear, the ball screw, the head, inner pad, the caliper, and the outer pad.

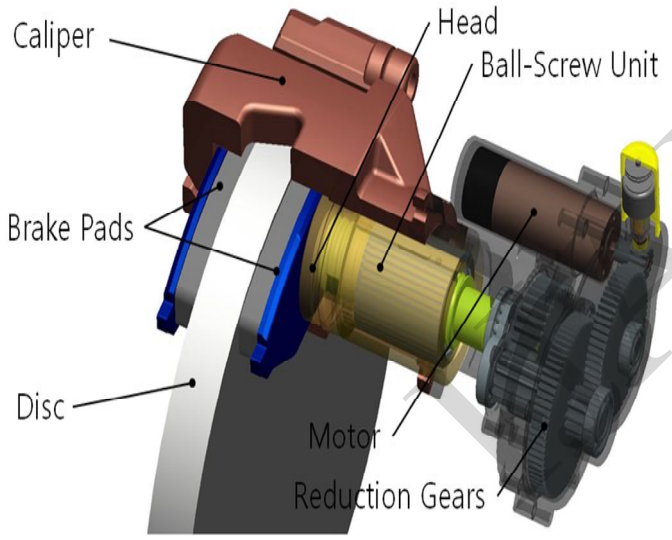


Fig.2. A mechanical part of the EMB system [8]

A torque for shaft is generated when the motor is rotating. The torque of the motor increases due to the reduction gear. The increased torque changes the direction of the torque from the rotary motion to the linear motion by a ball-screw unit. A linear motion transfers the torque to the head. And the inner pad pushes to the disk. Because the actuator part and the caliper part are tied, the power which pushes the inner pad changes the opposite direction of the inner pad movement. The outer pad is pulled to disk and the clamping force both sides of the rotating disk with the inner pad. The vehicle has brakeddue tothe clamping force.

B. Control Part

1) Hardware configuration

There is the H/W configuration for the EMB system. It is presented in Figure. 3. There are the current sensors for DC Link and 3 phase, 3 phase power bridges, FET Pre drivers and DC link in invertor. There are the power module, CAN(Control Area Network, ADC(Analog Digital Converter), RC filter and microprocessor in the control board. It is separated the controller and invertor by the photo coupler IC. The power module can supply the voltage 5V and 3.3V. The microprocessor is the MPC5643L of Freescale co. Ltd, 3 phase power bridge is FB4310 of IR co. Ltd. which can use max 150A. The current sensors are installed at phase A and B. The controller can detect the DC Link current and DC voltage. The circuit to detect the hall signal and encoder signal is installed.

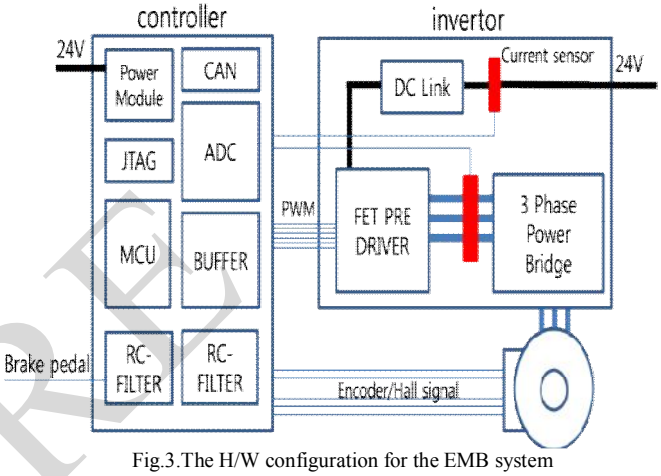


Fig.3.The H/W configuration for the EMB system

2) Software configuration

There is the S/W architecture for the EMB system. It is presented in Figure 4. The scheduler is operated by the 1ms timer interrupt. 1ms task, 10ms task, 50ms task, 100ms task in the scheduler are used. The software consists of the initialization function, the communication function, the hall/encoder detect function, the PWM (Pulse Width Modulation)function, the vector control function and the detect function of the input signal. The EMB system operates the self-diagnostic function and the signals are monitored by the CAN communication. The LPFs(Low Pass Filter) have the cur off frequency and sampling frequency are designed to remove the noise of the input signals.The vector control are calculated in a PWM interrupt routine to improve the motor performance.

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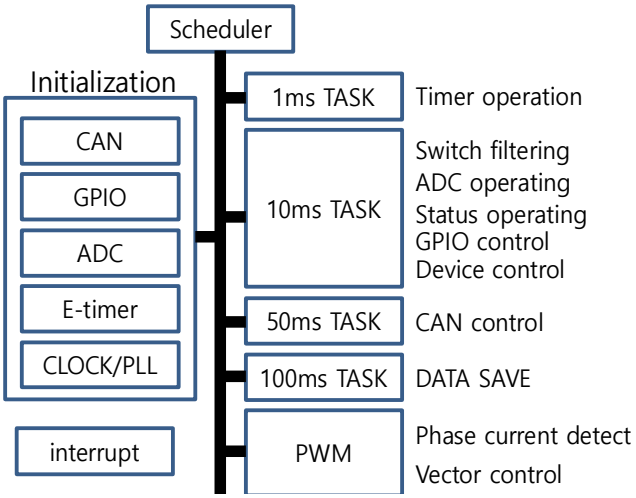


Fig. 4. The S/W configuration for the EMB system

3) Design Software

A position controller for the EMB is designed using a PI (Proportional, Integral) controller.The block diagram to control the EMB system is presented in Figure 5.

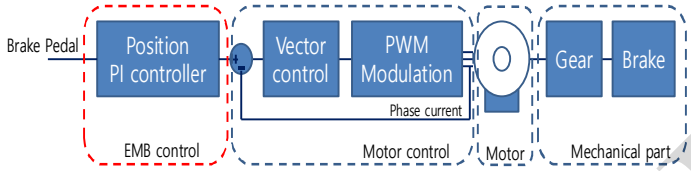


Fig.4. The block diagram to control the EMB system

The vector controller calculates the PWM values for the PWM modulation using the phase current from the motor. The PWM modulation function operates the motor. The input reference of the vector controller is the q axis current error between the result of the position controller and the phase current of the motor. The PI control equation is named after its two correcting terms, whose sum constitutes the manipulated variable. The proportional and integral are summed to calculate the output of the PI controller. Equation 1 is the final form of the PI controller.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau \quad (1)$$

Where the following nomenclature applies $u(t)$ is the controller output, K_p is the proportional gain, K_i is the integral gain, t is time, τ is the variable of integration, and $e(t)$ is the error between the q-axis current reference and the phase current.

C. EMB Simulation [5]

Figure 6 shows the EMB system designed using the MATLAB tool. The vector control method is operated in the motor controller. The load of the motor is given by the EMB model. The position controller is designed using the PI controller, and the result is used as the reference of the Q-axis current. The function of each of the labelled blocks is as follows:

- Reference position: The required position is set using a constant block.
- PI position block: The error signal is obtained by subtracting the reference position from the real position. For the PI control, MATLAB's library is used.
- Motor block: The electrical and mechanical equation of a PMSM.
- Vector control block: The inputs to this subsystem are the required values of the direct axis(Id), the quadrature axis(Iq) current and the real-time value of theta which is fed back. The direct axis component of the stator current produces useless compression force. Ideally, we would prefer if the direct axis component is 0. Hence, we set the required value of Id to a constant value of 0.
- Sinusoidal PWM block: This subsystem generates the six PWM waveforms for the FET circuit.
- EMB model: The load is modelled as an EMB whose value is denoted in force (N). This load force is used in the main motor subsystem to compute other quantities.
- FET circuit: A three-arm, 6-FETinverter circuit is implemented. The gating pulses (PWM) are provided by the sinusoidal PWM control subsystem.
- Scope blocks are used to observe the various waveforms in real time.
- The speed computed by the PMSM model block is in radians/sec. However, for the sake of user convenience, it is converted to RPM.
- Position block: The position computed by the theta of the PMSM.

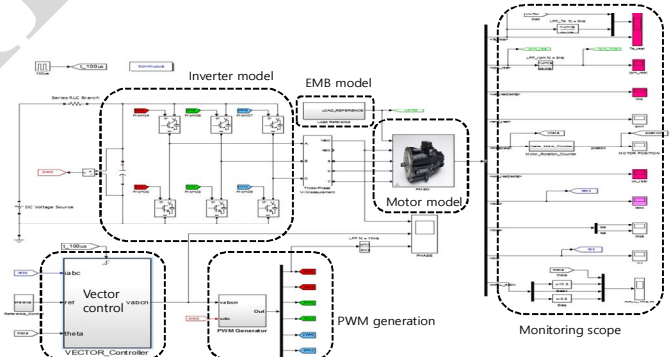


Fig. 6. EMB Simulation model in MATLAB

D. Initialization algorithm

The EMB system needs to compensate the pad abrasion. So the current for making the maximum torque is supplied to initialize the pad position. The initialization algorithm by the current can detect the position of the maximum torque. That is defined the maximum position of the EMB. The torque are made by the supplied current. Equation 2, 3are shown a relational expression between the torque and the current. The d axis current is zero because of the SPMSM (Surface Permanent Magnet Synchronous Motor). The pad position is always same.

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$$T_e = \frac{P}{2}\frac{3}{2}\emptyset_f i_{qs}^r \quad (2)$$

$$I_{dc} = \sqrt{i_q^2 + i_d^2} \quad (3)$$

Where the following nomenclature applies that T_e is the torque, $\emptyset_f$ is the magnetic flux, $i_{qs}$is the q-axis current,i_d is thed-axis current, and I_{dc} is the DC link current.

IV. Implementation of the EMB System

The EMB system is implementation as Figure 7. There are the mechanical parts, brake caliper parts, the motor control parts, the CAN monitoring parts, the debug in the EMB system. The force sensor is installed to measure the force at the pad when the EMB is operating. The force sensor can measure 50KN. Three FETs were connected in parallel to supply sufficient power to allow the inverter to supply the current required by the motor. The controller was controlled by the switch box and the CANoe tool. The CANoe panel is presented in Figure 8. It can control the torque, the speed, the position and the pedal rate. And it shows the calculated force and the current position. Depending on the selection, the motor is operated by encoder or hall signal. This system has diagnostic functions which are the over current, the under current, the over speed, the under speed, encoder error, hall error, the over voltage, the under voltage etc.

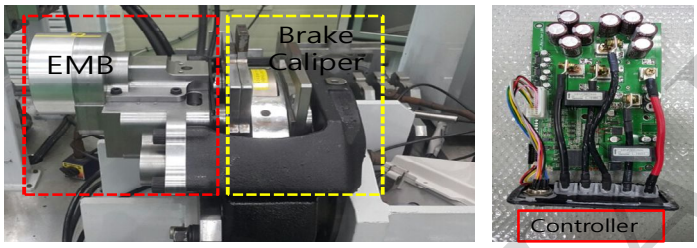


Fig. 7. The picture of the EMB system

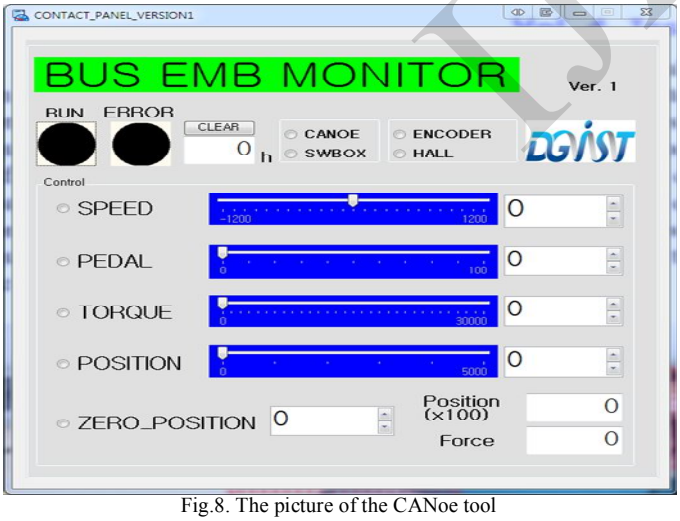


Fig.8. The picture of the CANoe tool

V. Experimental Results

A. Test Result of Initialization algorithm

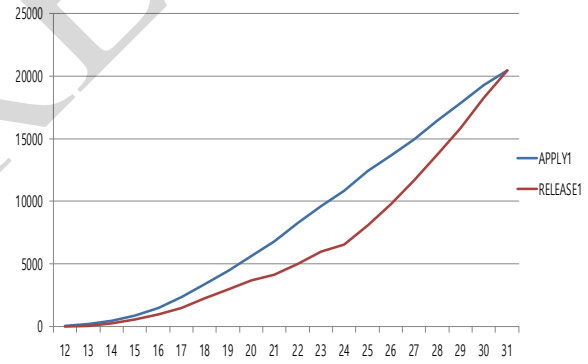
The current is supplied to verify the initialization algorithm. When the same current is supplied, the same force are measured. The current is supplied as the open loop. The results are presented in Table I. The supplied current is 370mA. When the current is supplied, the force is measured around 23KN. That is the maximum position which is the 32 cycle.

TABLE I. Test Result of the Maximum Torque

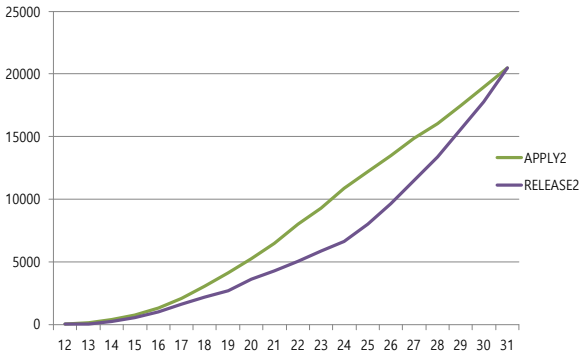
No	1	2	3	4	5
Force(KN)	23.0	22.5	22.7	23.2	22.8
No	6	7	8	9	10
Force(KN)	23.1	23.5	23.1	22.9	22.8

B. EMB Performance TEST

The EMB force is controlled by adjusting the pad position. The EMB force is measured when the EMB applies and when the EMB release. The force graph is presented in Figure 9. And the force data depending on the pad position is presented in Table II. There is the hysteresis curve in EMB system. The same force is measured at the same position.

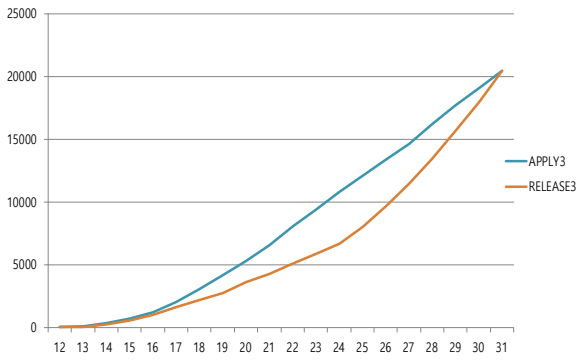


(a)



(b)

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(c)

Fig.9. Force graph depending on the position, (a) Apply 1, Release 1 (b) Apply 2, Release 2 (c) Apply 3, Release 3

TABLE II. FORCE DATA DEPENDING ON THE POSITION

Position		0	12	15	17
NO #1	APPLY1	0	30	880	2330
	RELEASE1	0	10	560	1490
NO #2	APPLY2	0	10	750	2100
	RELEASE2	0	10	560	1610
NO #3	APPLE3	0	10	670	2050
	RELEASE3	0	10	540	1610
Position		19	21	23	25
NO #1	APPLY1	4430	6810	9600	12400
	RELEASE1	2940	4140	5980	8080
NO #2	APPLY2	4120	6500	9300	12200
	RELEASE2	2700	4260	5870	7980
NO #3	APPLE3	4150	6550	9410	12100
	RELEASE3	2730	4240	5870	8000
Position		27	29	30	31
NO #1	APPLY1	14190	17850	19250	20460
	RELEASE1	11650	15850	18220	20460
NO #2	APPLY2	14850	17480	18950	20480
	RELEASE2	11480	15580	17770	20480
NO #3	APPLE3	14650	17710	19100	20460
	RELEASE3	11480	15670	17970	20460

VI. CONCLUSION

The EMB system which are the mechanical parts, the brake calipers, and the motor controller partsis designed and implemented. The brake system is nonlinear system which has the different clamping force depending on the pad position. The initialization algorithm goes well because the maximum torque are measured when the same fixed current is supplied.The clamping force of the EMB is controlled using the position of the pad. There is hysteresis curve when the brake applies and releases. The clamping force is same at the same position. So the EMB system can control the clamping force using the pad position

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