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Development of Motor and Controller for VVA Module of Gasoline Vehicle

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***Abstract*—** Due to environmental concerns, the recent regulation on automobile fuel economy has been strengthened. The market demand for efficient vehicles is growing and automakers to improve engine fuel efficiency in the industry have been paying a lot of effort. To improve the fuel efficiency, it is necessary to reduce losses or to improve combustion efficiency of the engine. VVA (Variable Valve Actuation) technology enhances the engine's intake air flow, reduce pumping losses and mechanical friction losses. And also, VVA technology is the engine's low speed and high speed operation to implement each of appropriate valve lift. It improves the performance of engine in the entire operating range. This paper presents a design procedure of DC motor and drive for VVA system and shows the validity of the design result by experimental result with prototype.

***Keywords*—**DC motor, Inverter, VVA, Electric Drive.

I. INTRODUCTION

DC motors have ever been prominent in various industrial applications because their characteristics and controls are simple. In an industrial point of view, the dc motor is still more than others at low power ratings. [1]

Due to the recent environmental problems, the automobile fuel economy regulations have been strengthened around the world, and market demands for higher fuel efficiency in vehicles is increasing. In order to improve fuel efficiency, the automobile industry has been devoting a lot of effort. To improve the fuel efficiency of engines, it is needed to improve the efficiency of the engine and reduce losses. VVA (Variable valve actuation) technologies enhance the flow of the engine intake, reduce pumping losses and mechanical friction losses. Through this technology, the engine could improve fuel economy. VVA technology is also driving the engine's low speed and high-speed operation to implement each of the valve lift is appropriate. In all operating regions, it improves engine performance. The vehicles by optimizing the gear ratio could improve fuel economy.

Motor and controller are located around the engine where the environmental temperature is -40~125 [℃]. The controller needs high reliability because the controller controls the engine directly. In this paper, the device, which has high operating temperature range, is selected. And also for the production, 8 bit processer was used.

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II. DESIGN OF DC MOTOR

Over the several years, demands for fuel economy and low emissions have become strict. To meet these needs, mechanical methods are being replaced with the power electronic methods in the automotive application. In recent years, attention is being given to VVA(Variable Valve Actuation) technology for solving the problem that improve efficiency in vehicles. VVA technology enhances the engine's intake air flow, reduce pumping losses and mechanical friction losses. And also, it is the engine's low speed and high speed operation to implement each of appropriate valve lift. It improves the performance of engine in the entire operating range.

First of all, rough design is conducted using magnetic equivalent circuit model [2]. Table 1 presents the designed parameters of the motor. In order to have simple control and characteristics, we selected DC motor.

TABLE I
THE DESIGNED PARAMETERS OF MOTOR

Items	Design variables
Motor type	4poles / 12slot DC motor
Driving type	PWM speed control
Magnet	Ferrite (9BE)

Through a finite element analysis, performance of the designed motor is checked out and specific configurations are determined. The flux line and the magnetic density distribution of the motor is expressed in Fig. 1. In a basic topology of 4 poles / 12 slots, ferrite magnet is applied to stator core. As can be seen in this figure, maximum flux density of stator yoke and rotor core is less than 1.6[T], which means each specific shape and size is designed well.

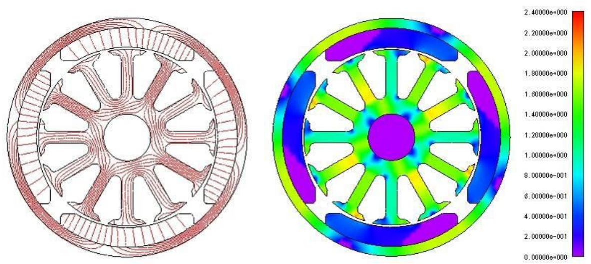
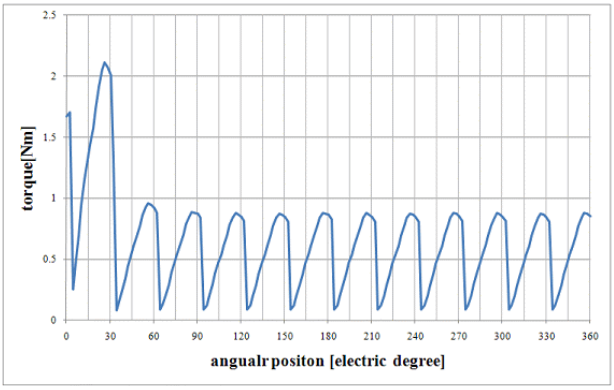
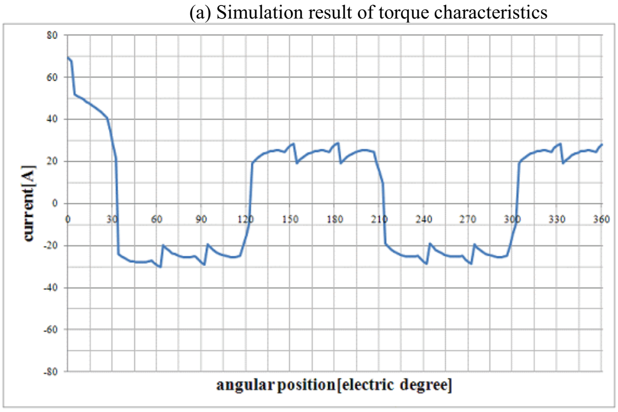


Fig. 1. Flux line and density distribution.

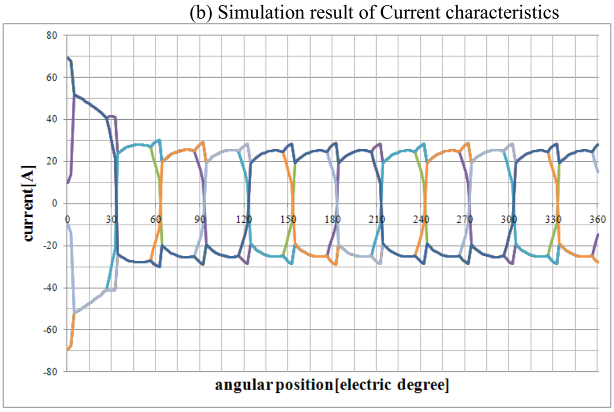
Figure 2 shows simulated results on the assumption that input voltage of 12V is applied to the motor. Average torque is about 0.5Nm and input current is predicted as 25A at rated condition.



(a) Simulation result of torque characteristics



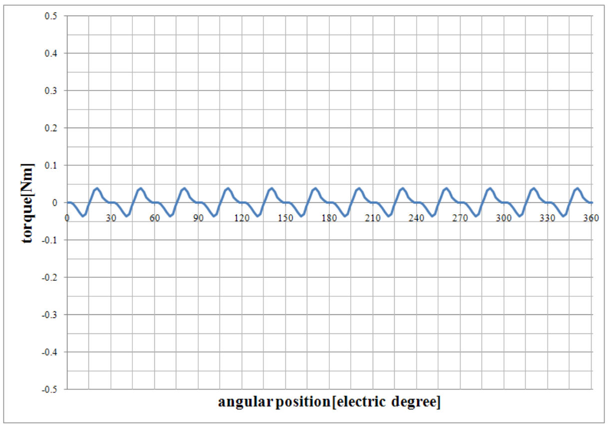
(b) Simulation result of Current characteristics



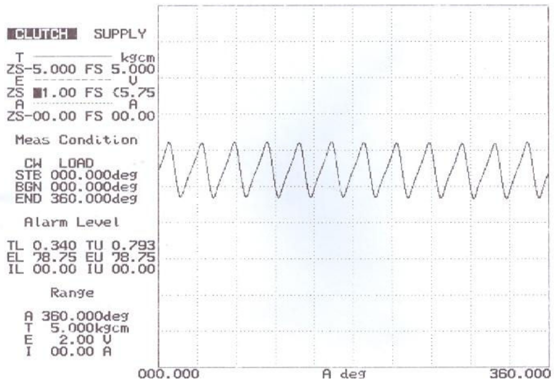
(c) Simulation result of Current characteristics

Fig. 2. Toque and curnet characteristics at rated speed of 5,000rpm.

Fig. 3 (a) shows cogging torque characteristics of designed motor. The duration of waveform is 12 cycles and 40[mNm], because the motor has 4 poles and 12 slots. Fig. 3 (b) shows an experimental result of motor cogging torque. The experimental result has same 12 cycles, but the torque is 65 [mNm]. The torque characteristics are little different because of the friction between the commutator and brush.



(a) Simulation result

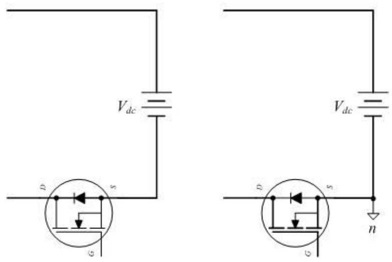


(b) Experimental result

Fig. 3. Cogging torque characteristics.

III. Design of DC Motor Drive

In the case of reverse dc-link voltage, it badly damages the drive. To protect the drive, it is essential to apply protection circuit. A relay is widely used for protection of reverse dc-link voltage in the electrical drives. But the relay is bulky and has a narrow range of operating temperature. It is important to reduce the size and to have a wide range of operating temperature in automotive applications. It is more important because VVA locates around the engine.



(a) Flow at initial power-on (b) Flow after initial power-on

Fig. 4. Flow at the forward operation.

To solve this problem, reverse voltage protection circuit with FET composed. Fig. 4 shows a circuit and the flow at the forward operation. At initial power-on, the drive operates through the body diode and then the FET is turned on by applying a gate signal.

The proportional-integral (PI) control scheme has been widely used for the speed control of motor drives. In this application, PI control scheme is used as the speed controller. Fig. 5 shows overall block diagram for VVA motor drive. In the block diagram, parameters with superscript * denote command value and K_b is back EMF constant.

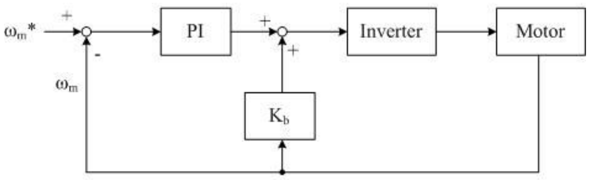


Fig. 5. Speed control block diagram.

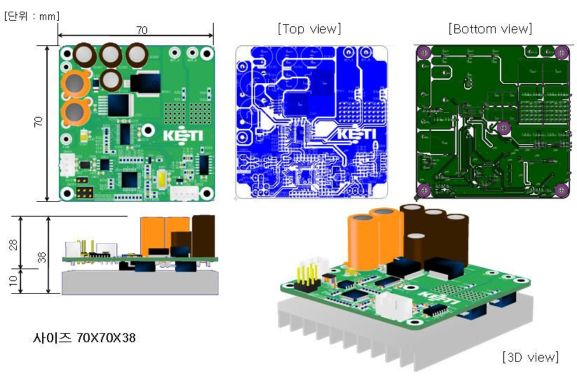


Fig. 6. Design of VVA motor drive.

In this paper, VVA is applied for the DC motor drive. The drive requires high density and high power, compared to traditional industrial drives. To meet these specifications, each part is designed by 3D. Including the heat sink, power density is 1.34 [kW/l].

Fig. 7. Control algorithm diagram for VVA system.

IV. Development of VVA System

In vehicle Drive driving Conditions, Once the driver's Demand torque is determined decided by Acceleration Pedal Position , in order to satisfy the actual inlet air flow rate (required air mass) which is to be flow into the combustion chamber should be determined (Figure.5) the actual inlet air flow rate (required air mass) into combustion chamber should be determined to meet it.

In general, the actual inlet air flow rate is determined based on the target air-fuel ratio (for example λ=1) according to driving conditions , but in real engine, volumetric efficiency considering air flow factors such as filling empty effect and compressing nature of air flow through the valves should be reflected in the decision of inlet air flow. Intake air flow in the actual engine is affected by the decision by the inlet air flow rate - in other words, the Volume metric efficiency considering filling-empty effects and compressibility of the air inlet valve according to the flow is reflected in.

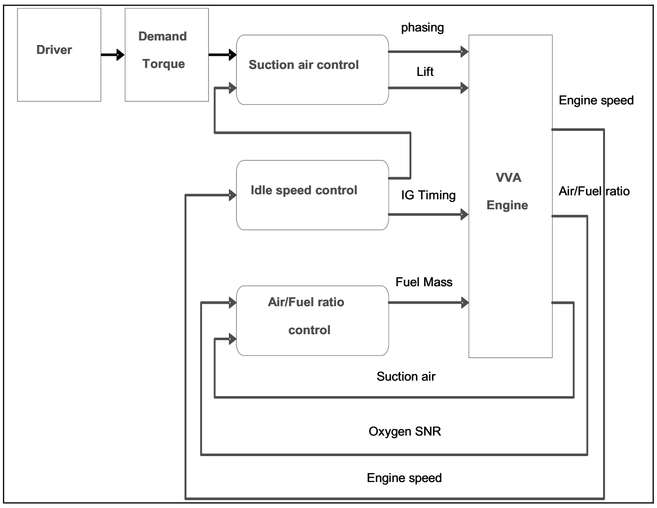


Fig. 7. Control algorithm diagram for VVA system.

Therefore, VVA Control System in this Study is designed to control the Valve Drive Motor by determining the valve lift size finally from calculation of the effective area of the actual inflow of air flow through the valve like Fig. 8. To this end, the below two methods were used to develop the logic and VVA Controller Unit which control the Drive Motor and calculate estimating the correction using Feed Back Sensor.

$$Trq_{dmd} = T_{cluth}(rpm) \times fac(PV) \quad (1)$$

$$Trq_{dmd} : demand\ troque \quad (2)$$

$$T_{cluth}(rpm) : clutch\ torque(T_{\max} - T_{\min}) \quad (3)$$

$$fac(PV) : factor\ w.r.t\ pedal\ value \quad (4)$$

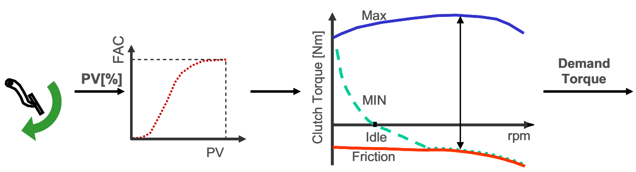


Fig. 8. Overall algorithm.

Fig. 9 shows photos of the VVA drive. To apply VVA, the drive was designed in the form of a round. The size of a drive is 75X70X38[mm], including heat sink. The rated power is 250[W] and the rated power density is approximately 1.34 [kW/l]. The VVA drive was tested extensively with dynamometer load and evaluated its performance over various tests.

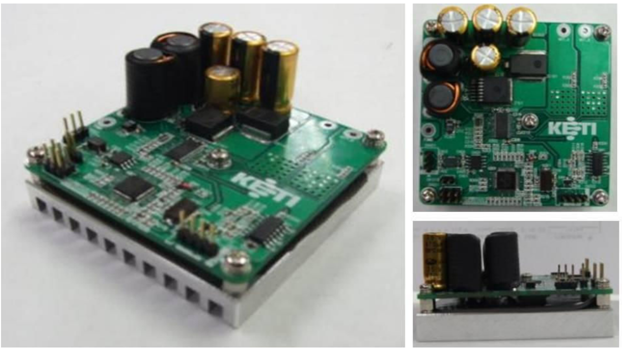


Fig. 9. Photos of VVA drive.

In consideration of production, 8 bit processor (MC9S08DZ32) was used. The Features of Speed-Torque-Current (N-T-I) in case of supplying 13.5V rated voltage are shown in Fig. 7. The satisfactory results are obtained the maximum efficiency 64% .

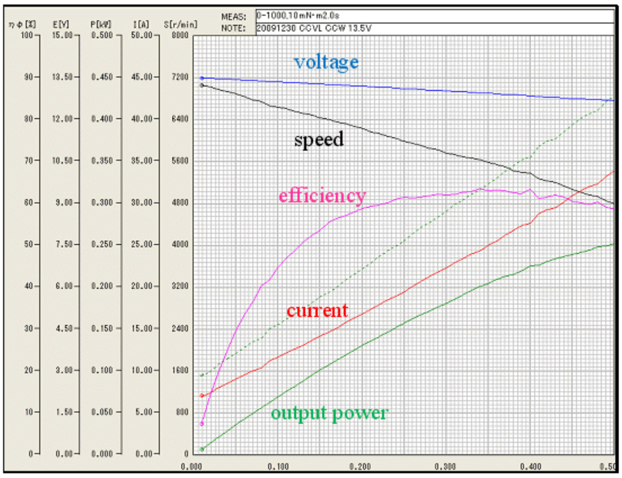


Fig. 10. NTI graph.

V. Conclusion

This paper presents a design and implementation of motor drive for automotive VVA. For the operation of VVA for automobile application, it is important to consider not only performance but also reliability. In order to enhance reliability, all parts of the drive, which the operating temperature range is over 125 degree, was chosen. And for the cost, the drive was simplified.

Through the experimental results, validity and quality of the reported designs are verified, and the motor and drive are obtained the maximum efficiency 64%. The developed BLDC drive has been successfully applied to VVA system.

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