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Vibration Reduction of 2-Phase Brushless DC Motor with the Adjustment of Switching Time

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Abstract: The vibration of a 2-phase BLDC motor is generally due to torque ripple and unbalance. This study examines the torque ripple by FEM simulation and compares it with experiment. To reduce the torque ripple, the switching time of the phase-current is adjusted. Motor parameters such as inductance, back emf are derived from the 2-dimensional finite element analysis on the magnetic field of the 2-phase BLDC motor. And the characteristics of the motor are analyzed by performing circuit simulation. The optimum switching time of the phase-current from the experiment is found and compared with simulation results.

Key words: Torque ripple, vibration, 2-phase, BLDC motor

INTRODUCTION

A BLDC (brushless DC) motor is easy to control the speed and has no mechanical contacts such as brushes for changing the current direction, so it has longer life than DC motor[1]. Due to its easy speed controllability, longer life, and high efficiency, the BLDC motor is widely used to home appliances like refrigerator, electronic oven, room air-conditioner, etc. Among the BLDC motors a 2-phase BLDC motor has simple structure and can be easily manufactured. It is more effective to save the production cost. The development and research on 2-phase BLDC motor is active now at several companies and universities[2].

To use as a part of home appliances, vibration and noise should be reduced as possible as can be. In case of 3-phase BLDC motor, some paper about vibration reduction has been reported[3], which proposed the method of displacing the Hall sensor from the original position to adjust the current switching time, so it can avoid mechanical resonance due to the switching frequency. But 2-phase BLDC motor has unique core shape that is not symmetric as like that of 3-phase BLDC motor, therefore the vibration of 2-phase BLDC motor is somewhat different from that of 3-phase motor. This study used the same method of the vibration reduction of 2-phase BLDC motor using the change of the switching time but main concerns are on the torque ripple not the resonance.

Analysis

Structure of 2-phase BLDC motor: The structure of a 2-phase BLDC motor is shown at Fig. 1, of which rotor material is ferrite magnet and core is skeleton type. It has

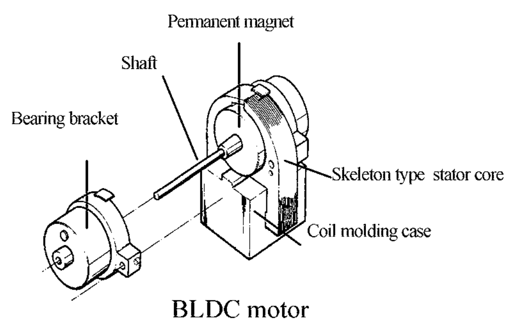

Fig. 1: Structure of 2-phase BLDC motor

one sensor for the detection of magnetic pole to switch the current direction. The driving circuit is placed in the coil molding. Bearing brackets have spherical sintered metals which can adjust self centering[4,5]. Core shape is not symmetric so that inductance can not be Fig. 1 configuration of 2-phase BLDC motor calculated easily. Therefore, an FEM package was used to calculate the inductance and back-EMF in this study.

Driving circuit: Generally the BLDC motor driving circuit can be simulated like Fig. 2. Where, V represents input voltage, I is the input current , e is the back-EMF, R is the resistance of the armature, L is the inductance and is the rotating speed[6,7].

Eq. (1) is of the driving circuit of the 2-phase BLDC motor.

$$\begin{bmatrix} V_a \\ V_b \end{bmatrix} = \begin{bmatrix} R_a & 0 \\ 0 & R_b \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} + \begin{bmatrix} L_a & 0 \\ L_b & 0 \end{bmatrix} \begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_a}{dt} \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \end{bmatrix} \quad (1)$$

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The torque is the sum of the existing cogging torque and EMF, which can be written as Eq. (2). Inductances and EMF are calculated using FE analysis.

$$T = \frac{1}{\omega}(e_a i_a + e_b i_b) + T_{cog} \quad (2)$$

Where, T_{cog} represents cogging torque.

FE analysis: Figure 3 shows the modeling of the 2-phase BLDC motor for FE analysis. Table 1 shows the mechanical and electrical specifications of the motor.

The inductance calculated from the FE analysis is 54 mH. Figure 4 shows the back EMF of the motor at 2,000 RPM, which is also calculated from the FE analysis. Figure 5 shows the cogging torque with rotation angle.

Table 1: Specifications of the model

	Value	Unit
Input voltage	12	V
Nominal speed	2,000	rpm
Stator inner diameter	26	mm
Lamination height	12	mm
Material of permanent magnet	Ferrite	-
O.D of permanent magnet	25.5	mm
Coil 570 turns/phase		
Rotational direction	CCW	-

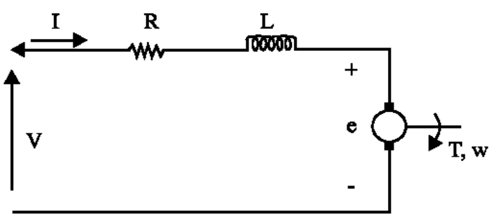

Fig. 2: Equivalent circuit of 2-phase BLDC motor

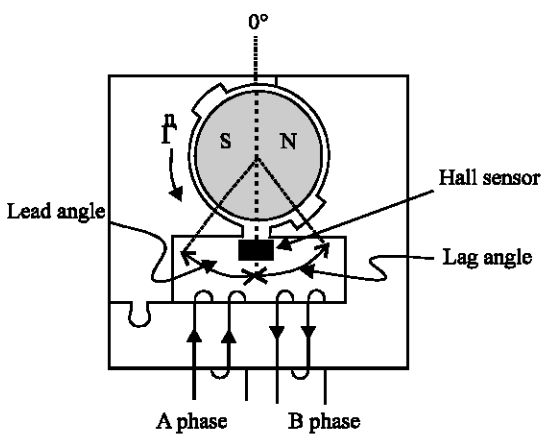

Fig. 3: Modeling of 2-phase BLDC motor

Comparing the back-EMF of the simulation with the measured one (Fig. 6), the simulation results can be said to be appropriate.

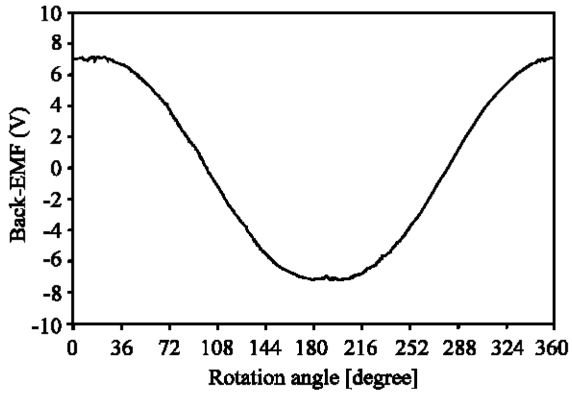

Fig. 4: Back-EMF

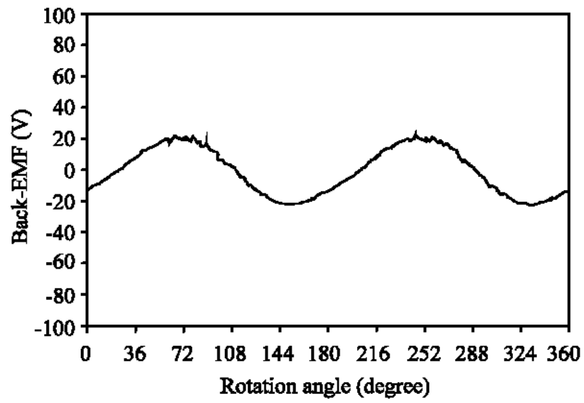

Fig. 5: Cogging torque

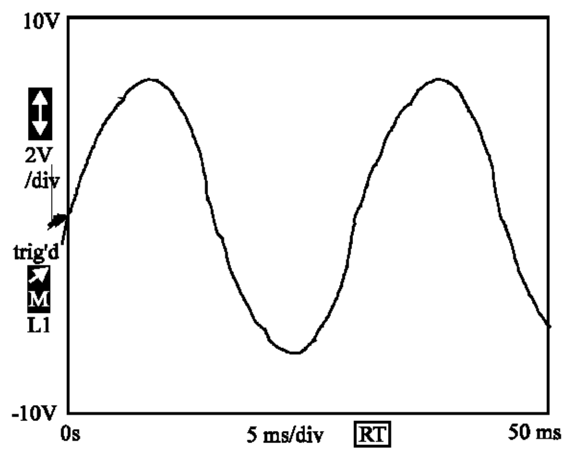

Fig. 6: Measured back-EMF

MATERIALS AND METHODS

Experimental set up: For vibration measurement with different switching positions, an accelerometer was mounted on the motor frame. A mechanical moving of sensor position for switching time adjustment is very difficult and we adjust switching time using μ-controller and circuit.

Block diagram for switching time adjustment of BLDC motor is shown in Fig. 7. A μ-controller receives hall IC signal of motor and generates switching angle we decided already.

To adjust the switching time for a circuit, Both lead angle and lag angel using the hall IC signal are generated. Figure 8 shows timing chart for switching time and Fig. 9 shows flow chart for this algorithm. At first, we initialize registers of μ-controller and decide switching angle. If the program is interrupted by hall IC signal, it is calculated switching angle by interrupt service routine. With variation the switching angle, an appropriate switching time can be obtained. At that lag and lead switching time, the current of the circuit was also measured.

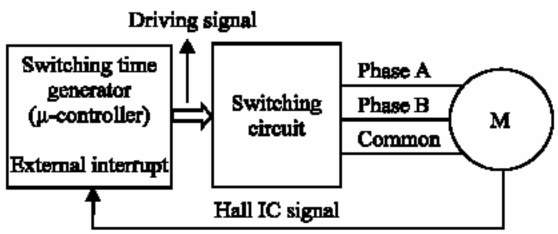

Fig. 7: Block diagram for switching time adjustment

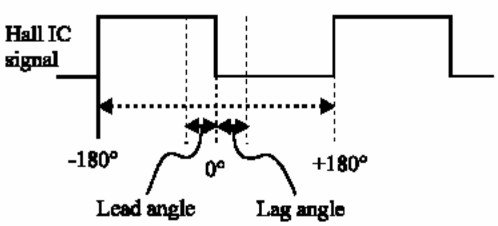

Fig. 8: Timing chart for switching time adjustment

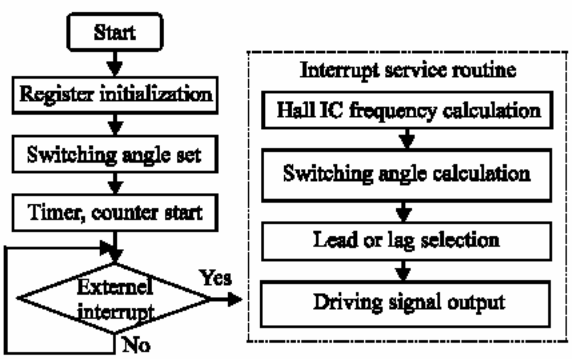

Fig. 9: Flow chart for switching angle generation

Experiment with constant voltage: At first, an experiment was performed with constant voltage. Figure 10a and b is the current signal with lagging and leading switching time. At lagging, there is a concave shape in the upper middle of the current waveform. At leading, there is a convex shape on the contrary. It means that the current at switching time is lower than the one at leading switching time under the same constant voltage. The rotating speed at lagging is lower than the one at leading. This means that the efficiency at leading is much better than the one at lagging. The torque ripple which affects the vibration of a motor is also greater at lagging than the one at leading.

Figure 11 shows the current shape calculated from the simulation, which is good agreements with the experimental result.

Experiment with constant speed: The torque ripple increases and the current with average torque decreases in the lagging condition (Fig. 12 and 13).

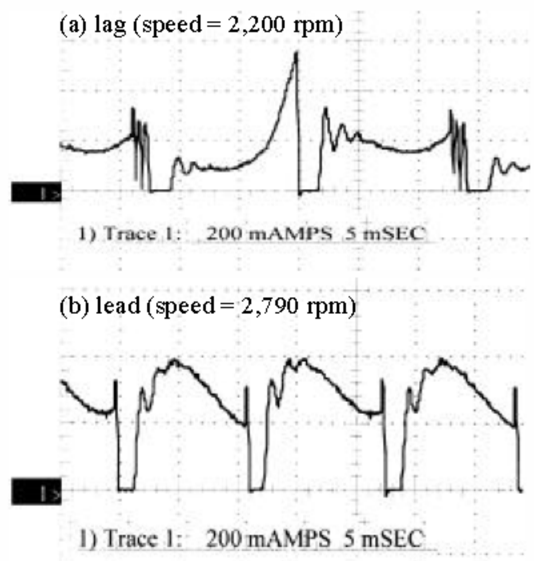

Fig. 10: Input current with lagging and leading switching time

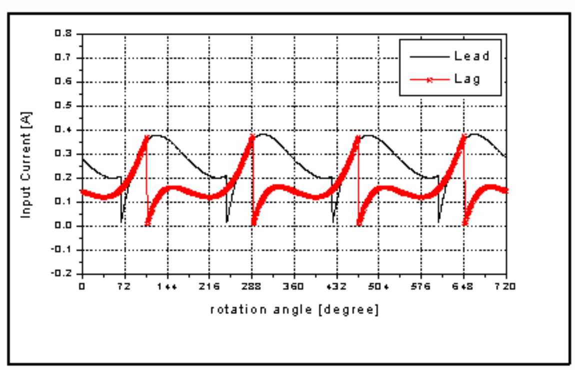

Fig. 11: Simulation of input currents with lagging and leading switching time

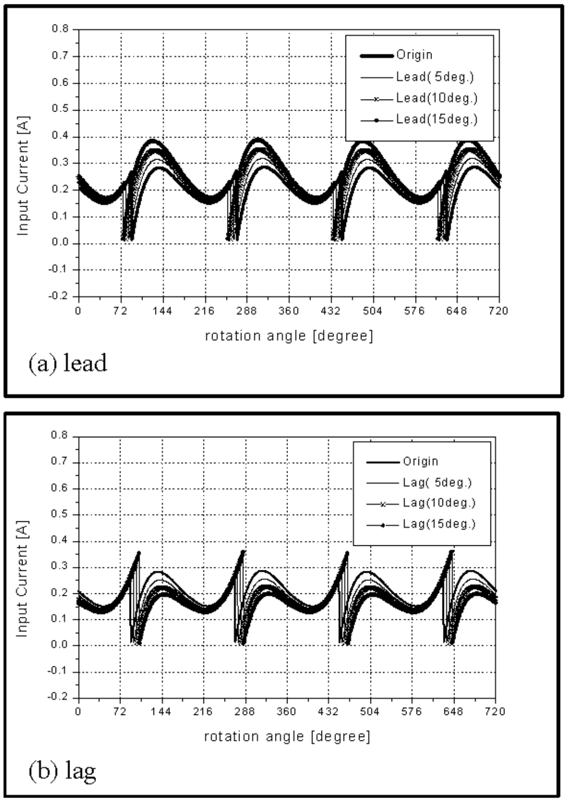

Fig. 12: Simulation of the currents with different switching positions

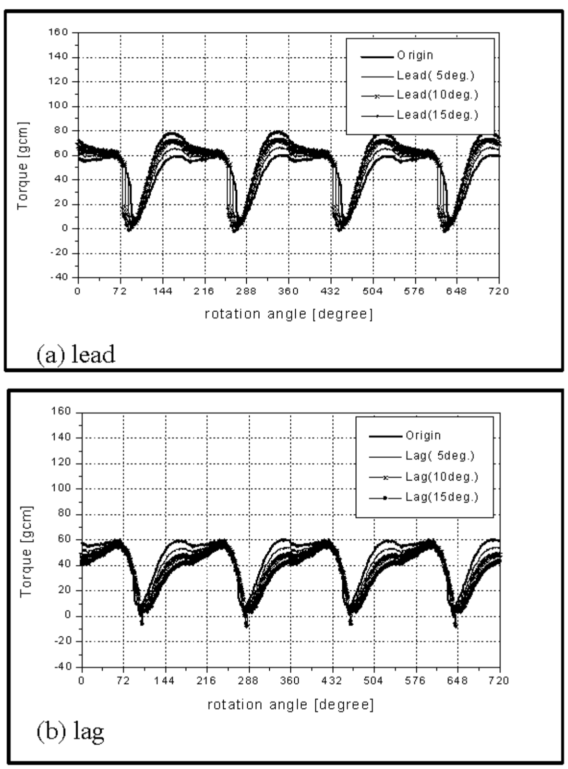

Fig. 13: Torques with different switching positions

Table 2: Experimental results of the vibration and the performance

Switching position (deg.)	Vibration amp (M s^{-2})	Input voltage (V)	Input current (A)
-27.8	0.411	14.90	0.35
-19.6	0.163	11.10	0.17
-12.8	0.186	10.60	0.14
5.94	0.183	9.80	0.15
28.47	0.320	8.60	0.18
53.3	0.308	8.50	0.27

When leading, torque and ripple is relatively better than those ones in the original switching position. From the simulation, the performance becomes the optimum when the switching position is placed at about 5-degrees ahead.

Table 2 show the measured values including vibration amplitude with constant velocity condition. This coincides with the simulation results considering the current shape and torque ripple as the main factors to the vibration and the performance of the motor.

CONCLUSION

The vibration reduction of 2-phase BLDC motor with the variation of switching time was examined by simulation and experiment. Comparing with the experimental results, the optimum sensor position which determines the switching time could be found.

In case of 2-phase BLDC motor, the main factor of the vibration and the performance was the torque ripple caused by current switching. Switching time is dependent on the sensor position. From the simulation with experimental result, the optimum position of Hall sensor which set the switching time was about 5 degrees ahead from the original position.

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