A Simulation Model of Hall Sensor Misalignment in BLDC Motors

Chung-Wen Hung
Department of Electrical Engineering, National Yunlin University of Science & Technology,
123, Sec. 3, University Road, Douliou, Yunlin, 64002, Taiwan

Chu-Lin Hsu
Department of Electrical Engineering, National Yunlin University of Science & Technology,
123, Sec. 3, University Road, Douliou, Yunlin, 64002, Taiwan
E-mail: wenhung@yuntech.edu.tw, B10100061@yuntech.edu.tw
www.yuntech.edu.tw

Abstract

A simulation model of Hall sensor misalignment in BLDC motors is proposed in this paper. The Hall sensor is popularly used in brushless DC motor to decide commutate and rotational speed. However, the accuracy of Hall sensor position is limited in most of BLDC motors, and it is lack of suitable simulation model for Hall Sensor installation misalignment. The details of simulation model are discussed in this paper, and simulation results are also provided to show the model isworkable.

Keywords: simulation model, BLDC motor, Hall sensor, misalignment.

1. Introduction

BLDC motors are popularly used nowadays due to its high power density, low maintenance requirement, and easy control. Most BLDC motors have Hall sensors which are used to decide commutation timing and estimate rotational speed. However, it is impossible to install Hall sensors in accurate position without error. This misalignment effect will cause torque ripple due to wrong commutation timing and incorrect speed feedback.

This phenomenon is highlighted in some studies and these papers tried to propose solution. [1] proposed a Hall-effect-sensor-based position observer to mitigate torque ripple in permanent-magnet synchronous machines, and the hardware and simulation validation showed the proposed algorithm is workable. [2] proposed an auxiliary circuit for BLDC motors, to reject the Hall sensor signal noise and capture time interval. The circuit is built in field programmable gate array, FPGA, and the experimental results show the circuit works as expecting. This work could be a good reference for BLDC motor control integrated circuit. However, those two studies didn't discuss any simulation. [3] focused on commutation behavior situation of BLDC motor, and proposed a simulation model in MATLAB. [4] presented an efficient simulation model for variable sampling system, which is caused by low resolution effect of Hall sensors. However, it is a lack of simulation model for the Hall sensor position misalignment.

2. The Simulation Method

To simulate the Hall sensors in BLDC motors, the rotation information, distance, is necessary. It is used to decide the hall sensor signals. The most of BLDC motor simulation models only provide the rotational speed output, so an integrator will be used to perform the rotation distance. As shown in Fig. 1, to simplify explanation, the pole pair number is set to 1; Hx indicates Hall sensor whether x is a, b or c. When the BLDC motor rotational angle arrives 0 or π radians, means the point O reaches origin or Ha, the output of Hall sensor A will change due to the change of magnetic

© The 2016 International Conference on Artificial Life and Robotics (ICAROB 2016), Jan. 29-31, Okinawa Convention Center, Okinawa, Japan

field direction. The detail is presented in Fig. 2. If without reverse, the output of the integrator is monotony increasing. However, only the angular information within 0 to 2π is used, so the remainder divided by 2π is useful for the decision of Hall sensor signal. Similarly, when point rotes 5π/3 or 2π/3 radians, the output of the Hall sensor B will change. Again, Hall sensor C will change at π/3 and 4π/3 radians.

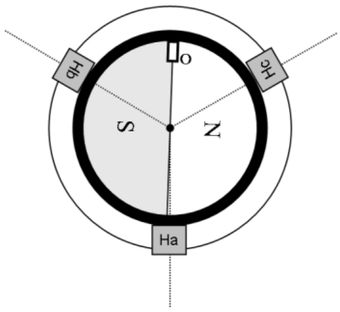


Fig. 1. Diagram of Hall-sensor and relative rotor positions

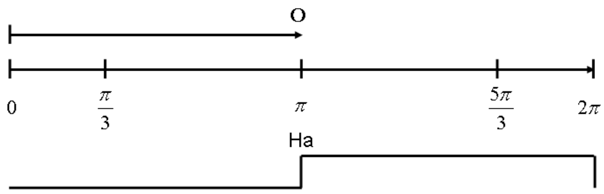


Fig. 2. The relationship between Rotation angle and Hall sensor output

3. The Proposed Simulation Model

As discussed in the previous section, an integrator is used to integrate rotational speed to rotational distance, which is equivalent to rotational angle; a remainder block is built to calculate rotational angle within 0 to 2π. This block comprises a divider, a rounder, and an adder. A relational operator is applied to decide Hall sensor signal. The simulation model is shown in Fig. 3. Note, to simplify the calculation, the output of the remainder block is ratio of 2π, and the second input of the relational operator is changed to 1/2 from π. The other relational operator could be skipped, because remainder function will change the output to zero when divisible. However, the output of Hall Sensor B is positive, when rotational angle is larger than 5π/3 or less than 2π/3. And again, Hall Sensor C output high when lager than π/3 and less than 4π/6. The details are shown in Fig. 4, and described as (1)-(3). Here, % indicates remainder operator and θ presents the integrated rotational angle.

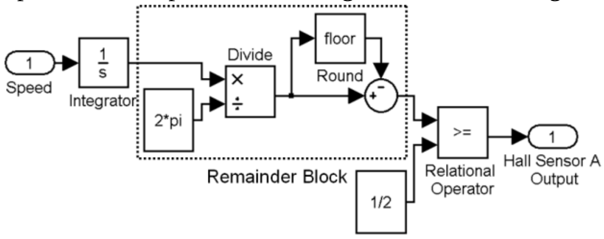


Fig. 3. Simulation model of Hall-sensor

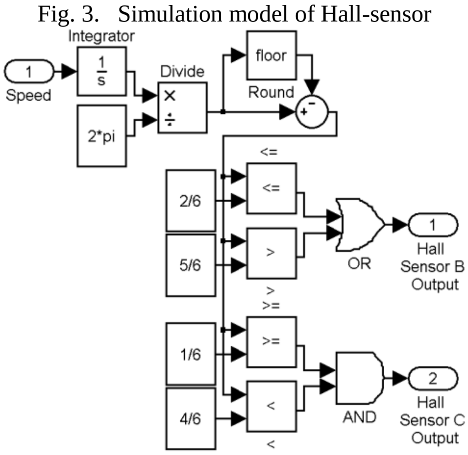
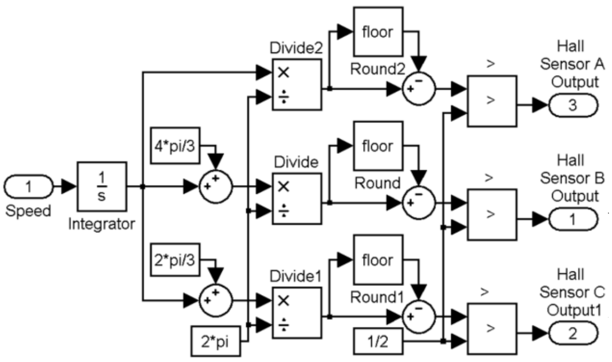


Fig. 4. Simulation model of Hall-sensor B and C

$Hall_A(\theta) = 0$, $= 1$,	if $(\theta \,\%\, 2\pi) < \pi$ if $(\theta \,\%\, 2\pi) \geqq \pi$	(1)
$Hall_B(\theta) = 1$, $= 0$,	if $(\theta \,\%\, 2\pi) \leqq 2\pi/3$, or $(\theta \,\%\, 2\pi) > 5\pi/3$ o. w.	(2)
$Hall_C(\theta) = 1$, $= 0$,	if $(\theta \,\%\, 2\pi) \geqq \pi/3$, and $(\theta \,\%\, 2\pi) < 4\pi/3$ o. w.	(3)



However, an equivalent operation could be performed with adding an angle shifter to the integrator output. For the Hall sensor B, the output is high till the point O runs to 2π/3, and then keep in low before it runs to 5π/3. If 4π/3 is added into to the integrator output, the summation will be fed into the remainder block and relational operator block, which are the same as Hall channel A. The outputs sill are equivalent to the previous model. Similarly, a 4π/3 shifter performs the same effect for channel C. The calculation requirement may not less than previous one. However, it is simpler and easier to understand. Moreover, it implies an advance what will be introduced in next section.

In most BLDC motor, the accuracy of hall sensor installation is limited, as presented in Fig. 6. The hall sensor may not be installed in correct position, it will cause wrong interval of HALL sensor signal. A novel simulation model is proposed to simulate this misalignment effect, and the position error is added to the two relational operators in Fig. 4. As shown in Fig. 7, the Hall sensor B channel is modified, and it can work well to reflect the misalignment effect.

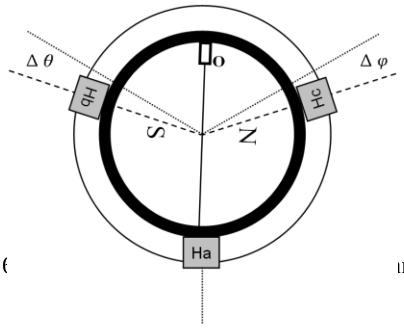


Fig. (ment

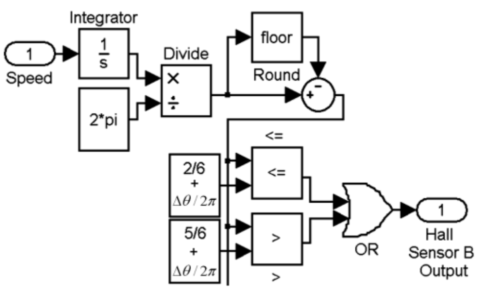


Fig.7. Misalignment simulation model of Hall-sensor B

However, misalignment effect could be simulated easier, if the previous equivalent simulation model is selected. Because rotor and Hall sensor are symmetric, only one shifter which is used to add position error is needed, as shown in Fig. 8. It is more intuitive and can avoid missing the other relational operator in Fig. 7. Note that, an extra shifter could be added into channel A if there is any position error for the Hall sensor A.

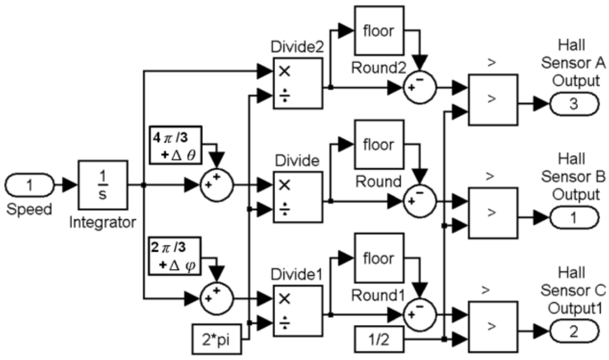
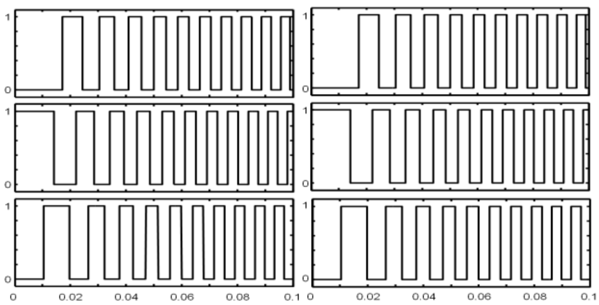


Fig. 8. Equivalent misalignment simulation model



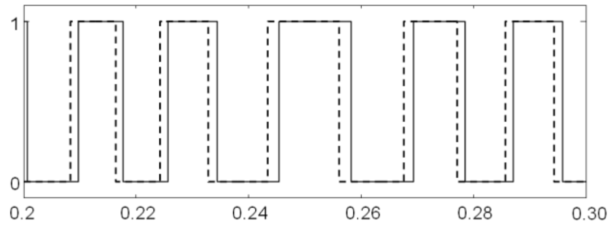


Fig. 10. Simulation result of Hall sensor B with misalignment

5. Simulation Results

To verify the proposed simulation model work well, the proposed model is add to the BLEDM DEMO model in Matlab Simulink. The input of the proposed model is the BLDC motor speed, and the output is Hall sensor output. Fig. 9 presents the Hall sensor signal comparison between the Matlab Simulink demonstrational and proposed models without misalignment. It shows that the two outputs of Hall sensors are the same. Next, to show the misalignment effect, the proposed misalignment model is used to replaced, and the channel B result is shown in Fig. 10. Obviously, the proposed simulation model could simulate the misalignment effect well.

6. Conclusion

A Simulation Model of Hall Sensor Misalignment in BLDC Motors is proposed in this paper. For most BLDC motors, it is very difficult and expensive to install Hall sensors in correct position accurately. And it will cause torque ripple and wrong speed feedback. The proposed model could simulate exactly this misalignment effect, and it is can provide a good simulation reference to engineers for designs of BLDC motor controllers.

Acknowledgements

This work is partially supported by the Ministry of Science and Technology, ROC, under contract No. NSC 103-2622-E-224-056 and 104-2221-E-224-012.

References

1. P. B. Beccue, S. D. Pekarek, B. J. Deken, and A. C. Koenig, Compensation for Asymmetries and Mis-alignment in a Hall-Effect Position Observer Used in PMSM Torque-Ripple Control, *IEEE Transactions On Industry Applications,* Vol. 43, NO. 2, MARCH/APRIL 2007, pp. 560-570.
2. C.-W. Hung and J.-H. Chen, A Hall Sensor Auxiliary Circuit with Noise Rejection and Time Interval Capture Functions for BLDC Motors, *Sensor Letters,* Vol. 10, 2012, pp. 1178–1184.
3. B. Tibor, V. Fedák, and F. Ďurovský, Modeling and Simulation of the BLDC Motor in MATLAB GUI, *in Proc. 2011 IEEE International Symposium on Industrial Electronics (ISIE),* 27-30 June 2011 pp.1403-1407
4. C.-W. Hung, C.-T. Lin and C.-W. Liu, An Efficient Simulation Technique for the Variable Sampling Effect of BLDG Motor Applications, *in Proc.33rd Annual Conference of the IEEE Industrial Electronics Society*, Nov. 5-8, 2007 (Taipei, Taiwan, 2007), .pp. 1175 - 1179

© The 2016 International Conference on Artificial Life and Robotics (ICAROB 2016), Jan. 29-31, Okinawa Convention Center, Okinawa, Japan