Chapter 6

Discussions and Conclusions

The software simulation and hardware experimental results of the sliding mode estimator for sensorless BLDC motor in speed control are discussed in section 6.1 and section 6.2, respectively. Finally, the conclusions and future work will be given in section 6.3.

6.1 Discussions of the simulation results

The simulation results have been shown in Chapter 5. Among these four case simulations, some situations should be discussed. Therefore, the discussions are divided into three categorizations: the modeling of the BLDC motor, testing estimator and sensorless control.

The electrical torque ripple due to phase commutation in BLDC motor could be found by inspecting particularity and the reason has been analyzed in [15] and [16]. Theoretically, two phases should be excited at one time. It is impossible to produce the electrical torque ripple. The rates of conducted and decayed phase currents are the same; while the rates are different in practically. Besides, the method of the Matlab®–Simulink® operation using fixed-step calculation leads to the fact that the simulation can not calculate each step at the same time. Based on the two reasons above, the electrical torque ripple is produced typically.

The discussions of the testing estimator are composed of angular velocity and position. In angular velocity estimator, if the sliding gain l_1 is determined, the estimated current error will be approached to zero as fast as possible. In other words, the system of the estimator will be entered sliding surface quickly. What follows are the back-EMFs Z_α and Z_β, the low pass filter's outputs of the sliding equivalent control gains, which will be obtained immediately. Therefore, the estimated angular velocity will be calculated within 0.1 second. Moreover, its position will be acquired slightly later because the effect of low-pass filters delayed.

The discussions of sensorless control include four categorizations: estimated angular velocity, position, motor and driver, and PID controller. First, the estimated back-EMFs error keeps nearby zero after starting sensorless control so that the variation of estimated angular velocity is small. Second, the estimated angular position has several errors compared with the actual one. With the use of compensator by Stateflow® toolbox, the estimated angular position error can be eliminated. Furthermore, according to the compensated position, the driver can switch the six inverters without confusing sequence proposed in section 3.1. Therefore, the performance of each phase does not have any serious variations at the instantaneous switching when the sensorless control occurs.

Finally, the linear controller, PID controller, is determined as a speed controller however the estimator design is the focus in this thesis. Actually, the non-linear terms of the estimated errors are limited no matter in case (1) or case (2). The vibrated phase currents occur after the sensorless control is switched, which is shown in Figure 5.11 and Figure 5.27. However, the model of the BLDC motor in software simulation does not include the following two situations: start up and reversal rotating. If one of them happens, the switching sequence of the driver will be confused immediately. Besides, the output of PID controller should not be a zero or negative value because the hyteresis current could not become zero or negative at a constant velocity theoretically. Consequently, the results after 0.7 second are presented in case (3).

Different from the case above, the failure case is verified to see whether at transition the sensorless control is workable or not. It is obvious as in the experimental results that this method has its limits and makes the results imperfect.

6.2 Discussions of the hardware experimental results

Three reasons make the experimental results not very well: lower sampling rate, measurement errors exists, mechanical friction force problems.

The reason why xPC target is used is that higher sampling rate than RTW in real time control is employed. Nevertheless, the actual sampling rate is just 10 kHz so the results are not good enough. If the sampling rate can be higher, the estimated current errors will be approached to zero rapidly and the estimated angular velocity will be more accurate as soon as possible.

The measured currents should be full of noises, maybe caused by the electromagnetic interference (EMI), connector plugs and conducting wires. It is not good to set up the low pass filters filtering these noises because the measured currents delay will occur.

The mechanical friction forces exist in motor itself and the coupled bearing even if no loading torque is added. The mechanical friction forces are also non-linear terms being entered into the whole speed closed loop control system and they can not be eliminated by sliding mode theory.

6.3 Conclusions

The sliding mode estimator for sensorless BLDC motor in speed control is proposed in this thesis and this method is workable in the simulation. The hardware experimental results also prove the implementation of this method. However, the whole speed control theory can be partly improved with regard to some shortcomings.

First, the speed controller should be used non-linear control algorithm to eliminate non-linear noises. For an example, adaptive control could be employed in the future.

Second, the measured signals, currents, velocity and voltages could be rapidly transformed into digital signals after detection. Therefore, the whole algorithm will be digitized, which may assist in eliminating noise effectively.

Finally, the hardware experiment can be improved in terms of increasing the sampling rate at least over 20 kHz. A possible method is to use the digital signal processing (DSP) board, which has been developed completely, so the sampling rate can reach 120 mega-instructions per second (MIPS).

Consequently, the main advantage of the method proposed in this thesis is that only currents and voltages are measured without the detection of back-EMFs and then the angular velocity can be estimated. On the contrary, the effects of the measured error are also seriously.