Sensorless control of a BLDC Motor

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Contents

Chapter 1

Theory

1.1 Basics of a BLDC Motor

Brushless Direct Current (BLDC) Motors are actuator types that have gained in popularity in the recent years. This is mostly due to their better characteristics and performance [2]. As their name indicated, these motors do not have brushes as regular DC Motors have to change the polarity of the magnetic field. But to make them rotate it is still necessary to create a rotating magnetic field. Usually this happens electronically with switches. The circuitry needed for that is a triple H-Bridge as can be seen in figure 1.1.

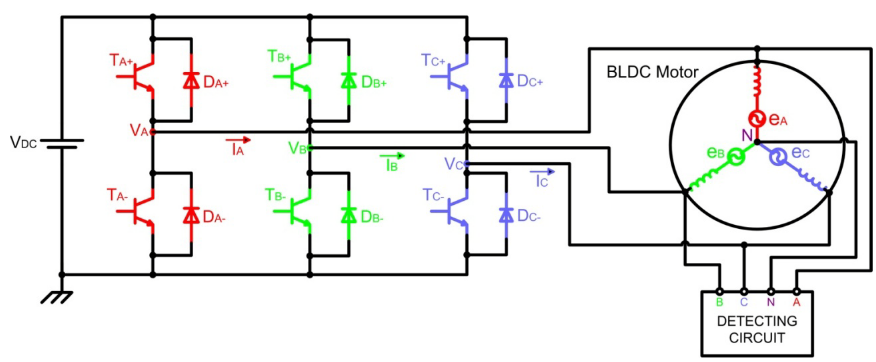


Figure 1.1: Triple H-Bridge for driving a BLDC Motor

The ideal signal to drive a BLDC Motor are three 120 phase shifted sinusoidals. With the triple H-Bridge this signal can be approximated by three 120 shifted rectangular wave forms. This leads to six states unique states for the switches, which need to be cycled through (commutate) sequentially. This states are shown in figure 1.2.

By varying the voltage of the phase that is in a high state, it is possible to control the speed of the motor. This can be achieved, in a digital circuit, by a pulse width modulated (PWM) signal.

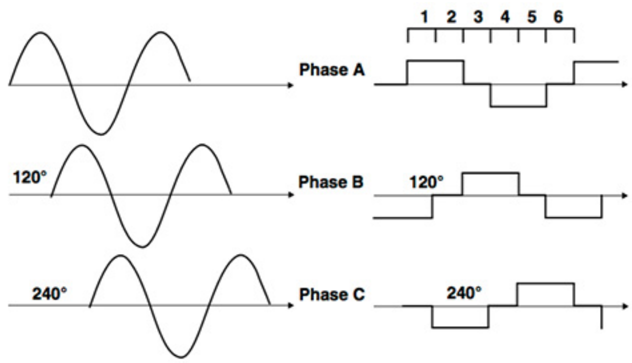


Figure 1.2: Input signal to drive a BLDC Motor

The challenge in implementing such a controller is to find the perfect timing in which to switch to the next state. This timing instance is influenced by speed, but also disturbances from the outside world and asymmetries in the motor itself. To have the motor generate torque reliably, it is necessary to commutate dependent on the rotor position, and thus a good estimate of such is key to having a good controller for a BLDC Motor.

1.2 Sensored vs. Sensorless Methods for position estimation

As mentioned previously, for reliable speed control of a BLDC motor it is essential to have a good estimate of the rotor position. There are sensored and sensorless methods to achieve this.

In sensored methods, typically hall-effect sensors are used to measure the magnetic field of the passing rotor. For commutation, three equally spaced sensors are necessary, to determine the right commutation instance. This method has some disadvantages though. If the sensors are not spaced very precisely in the right position in the motor, the commutation will be off. This leads to additional power losses due to the fact that the wrong commutation time, will have a breaking effect on the motor. Another disadvantage is that such sensors can not be made arbitrary small, and thus influence the size of a BLDC motor.

In sensorless methods the electromagnetic influence of the rotor in the generated field is used to estimate its position. The basic principle is induction, where a changing magnetic field induces a current into a wire. The changing magnetic field is produced by the permanent magnets in the rotor, while it is rotating. The conducting material are the phase coils of the stator. This effect is well known in the electric drive community and is termed Back Electromotive force (BEMF). Since the BEMF is only generated while the motor is running, starting it up can not be achieved with this method. Other strategies need to be used to get the motor spinning initially.

1.3 Back Electromotive Force - BEMF

In every state of the triple H-Bridge, two phases are always driven. One to the high potential and one to the low potential and thus the BEMF will not have a influence on those. The third phase is left floating, which allows the BEMF to induce a current into it. The current or the potential change which goes along with it are measurable.

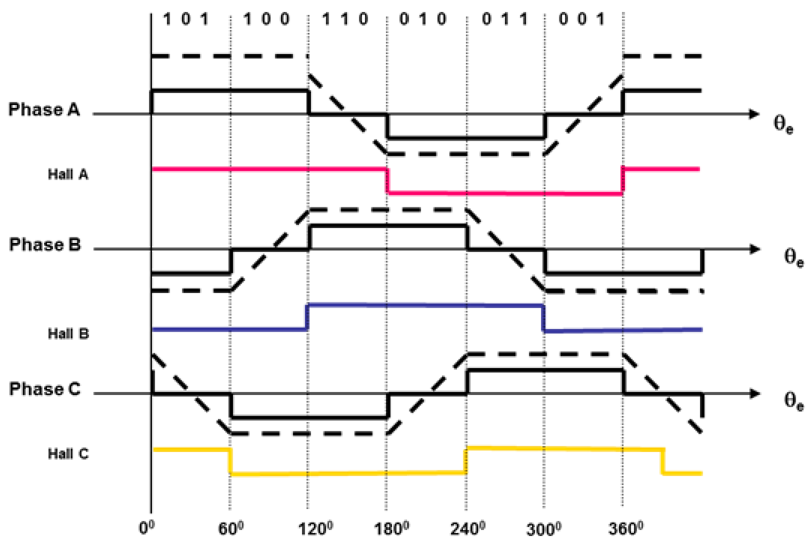


Figure 1.3: Phase Voltages during Commutation

In figure 1.3 the phase voltages are shown over the input signal as dashed lines. The BEMF is visible during the floating periods of each phase. While the motor is driven, the BEMF is referenced to the Motor Neutral Point N, shown in figure 1.1, which is usually not the same as the ground potential of the triple H-Bridge.

1.4 Integration Method

There are multiple different methods using the BEMF to find the right commutation instance. The method implemented in this project work, is the Integration method. The Integration method find the point, where the BEMF crosses the neutral point of the Motor and starts to integrate it. When this integration reaches a threshold commutation is done.

The area under the curve stays same for different speeds, which is indicated in figure 1.4. An advantage of this method is that is even works for low speed, since the integration of small BEMF signals, still reaches significant values.

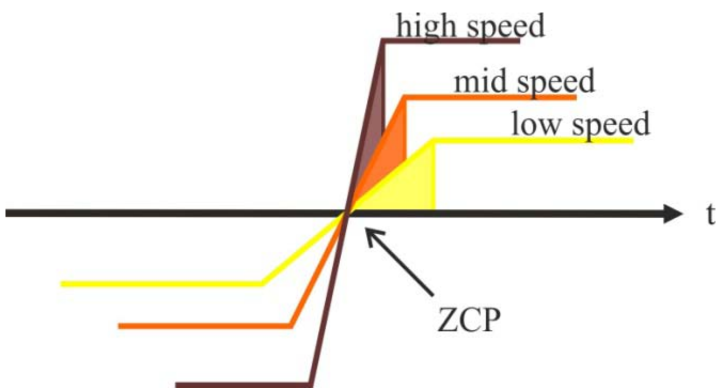


Figure 1.4: Integration Method

Chapter 2

Hardware/Software Implementation

2.1 Microcontroller

The Microcontroller used to implement the logic for the proposed electronic speed controller is the AVR Atmega328p. It is the standard chip on the Arduino platform and for ease of circuit connections this Arduiono Pro is used as a form factor. The μC can generate six hardware PWM signals and has 6 ADC inputs. This is more then sufficient to control the triple H-Bridge and measure the necessary BEMF signals. The ADC has a range from 0 V to 5 V. Thus the signal needs to be conditioned before it can be measured from the ADC.

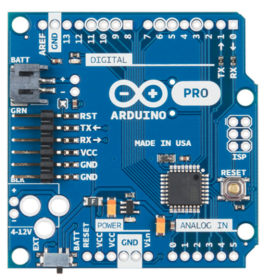


Figure 2.1: Arduino Pro with AVR Atmega328p

2.2 Measurement Circuit

The triple H-Bridge has a supply voltage of $VCC = 9\,\mathrm{V}$ also gives the range of possible BEMF readings. Since the ADC can only measure in the range of 0 V to 5 V, a voltage divider needs to reduce the magnitude of the phase voltage. From the proposed circuitry in figure 2.2 reduces the output to about 35% of the actual value, which allows a maximum measured value of 3.2 V. To further reduce the risk of damage to the ADC by voltage spikes, which do occur in inductive loads, a Zener Diode, which has a conducting voltage of 4.7 V is connected parallel to R_2.

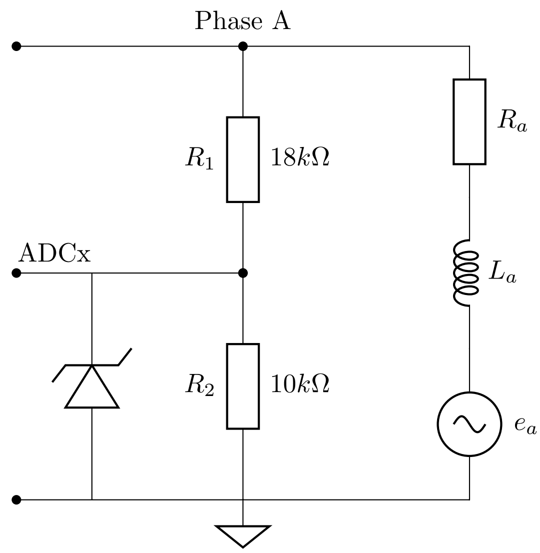


Figure 2.2

The measurement we obtain by this circuit is referenced to ground. As mentioned previously, the BEMF is actually referenced to the neutral point of the motor. To avoid creating a virtual neutral point outside of the motor, to have the right reference, it is also possible to only measure the BEMF during PWM off time. During this periods, the neutral point of the motor is the same as the ground potential.

2.3 Software Implementation

To get the motor spinning and start the process of measuring the BEMF, Timer0 was used with a frequency of 16 MHz to implement forward commutation. In this process all states are cycled through with a fixed time between them. For the three hardware PWMs the Atmega328p Timer1 and Timer2 were used with a frequency of 7.81 kHz. One of these PWMs creates a regular interrupt when switching to low. During this interrupt the ADC measurement can be triggered, to ensure the measurement is referenced to ground.

Chapter 3

Results

3.1 Proof of Concept with Oscilloscope measurements

The first step in testing the feasibility of the proposed controller was to check the quality of the BEMF. During this phase it became clear, that it is not easy to get a good BEMF with forward commutation. Figure 3.1 shows that there is hardly any trapezoidal form in the BEMF.

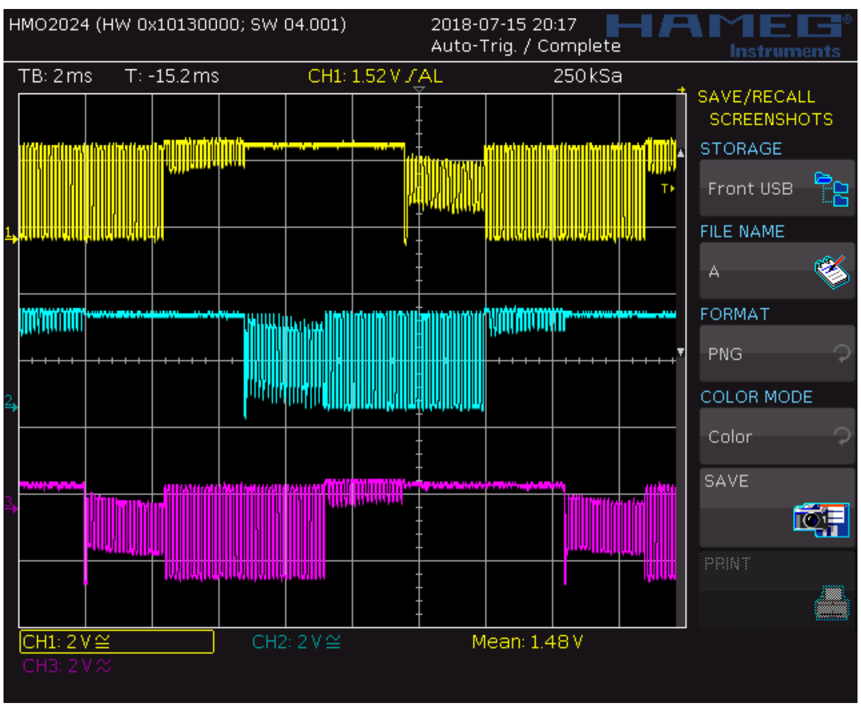


Figure 3.1: Back EMF of forward commutation

To discard any issues with the motor under test, the same measurement of the BEMF while using sensored commutation was taken. Figure 3.2 shows that the quality of the BEMF is still not perfect, but better. The rise and fall of the BEMF are clearly visible but they are not symmetrical. This could be caused by either a asymmetrical motor setup, due to manufacturing issues, or commutation is still not at the right instant. The would support the hypothesis that the hall effect sensors are not at the exact right position for perfect commutation.

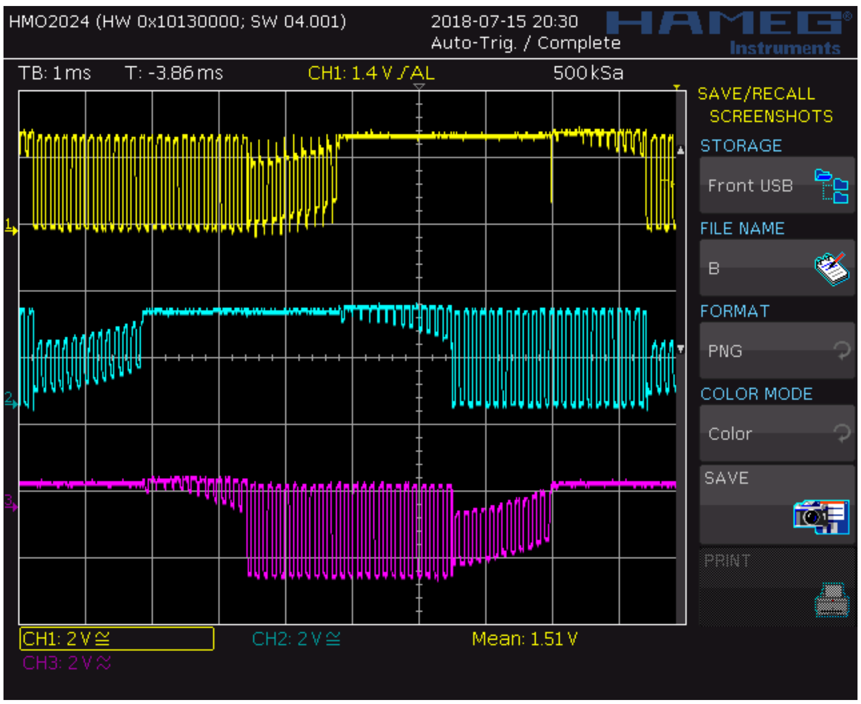


Figure 3.2: Back EMF of sensored commutation

To clarify reasons for this behavior even further, finally an industrial electronic speed controller was used to commutate the motor sensorless. The industrial ESC takes the same type of signal as stepper-, or servo motor. The results that this measurement revealed were very promising as can be seen in figure 3.3.

The BEMF is perfectly symmetrical which allows for the conclusion that there are no asymmetries in the motor. This set of measurements again emphasize the problems that sensored commutation can have if the manufacturing accuracy can not be met.

Since we have to use forward commutation to speed the motor up to a point where the BEMF is good enough to start the integration method, the next step is to find a good start up procedure.

It is clear that the quality of the BEMF at the operating point in figure 3.4

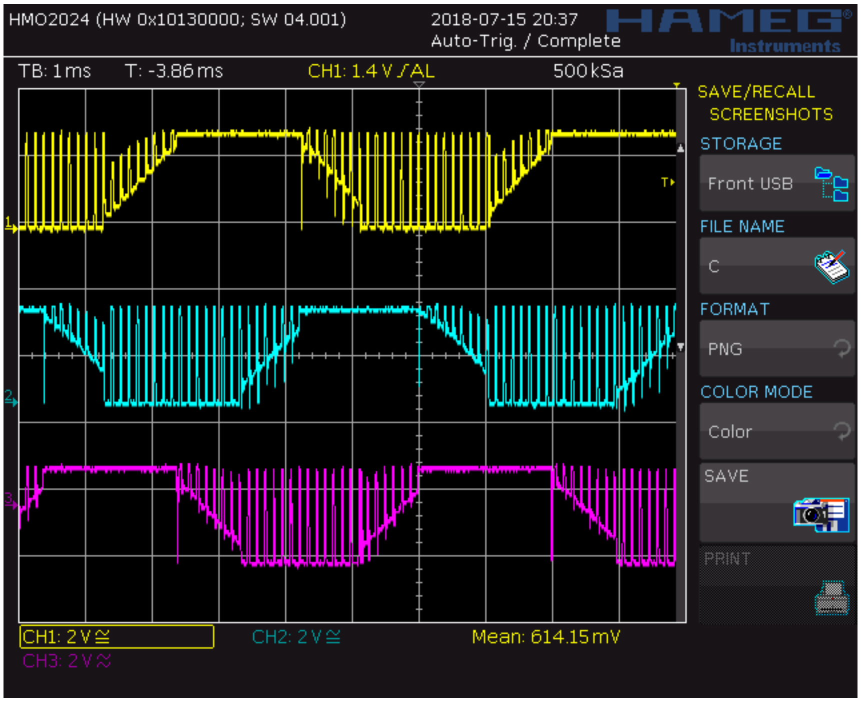


Figure 3.3: Back EMF of sensored commutation

is still not perfect, but it is good enough to get the integration method going.

3.2 ADC Measurement

To verify that the ADC measures the BEMF at exactly the right timing, the next step is to visualize some readings. For that the ADC writes measured data into a shifting buffer. This is necessary since the serial communication interferes too much with the μC. With this method it is possible to collect data for a couple of cycles stop the motor and send the whole buffer.

Figure 3.5 shows that the measurement scheme, measuring at the PWM off times, does in fact work.

3.3 Commutation instance estimation

After the μC has the capabilities to measure the BEMF of the three phases of the motor, what is left to be done, is to use this information for predicting the next switching instance. For that purpose the integration threshold needs to be found for rising and falling BEMF for every phase. To visualize the output of the prediction algorithm, a trigger signal is toggled every time the instance is found.

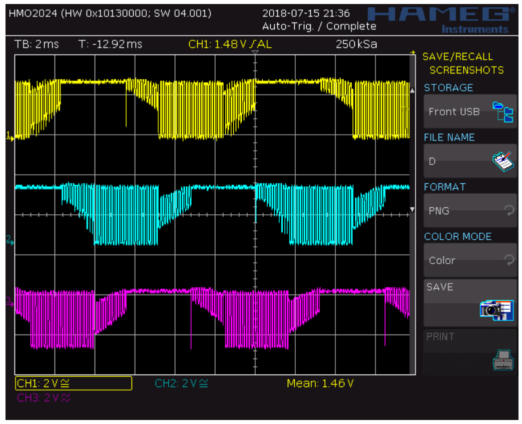


Figure 3.4: Back EMF after start up procedure

The accuracy of this method depends highly in the threshold value. If the threshold is not right, the BEMF becomes unsymmetrical and falling and rising BEMF will reach the threshold in different timing instances. This will let the motor stall. In figure 3.6b it can be seen, that due to the unsymmetrical BEMF the instance for the falling BEMF is a little to early. When the estimator actually decides the switching instance this should stabilize and the BEMF should become perfectly symmetrical. Since the right threshold value for the test setup could not be found, this could not be proven.

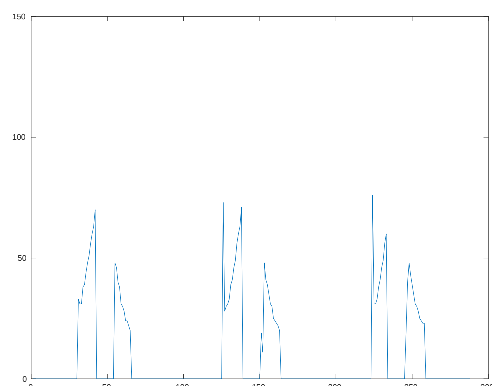
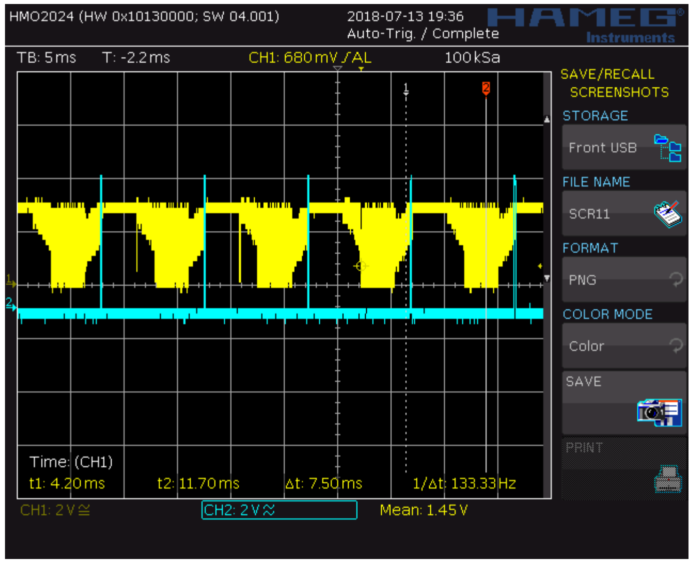
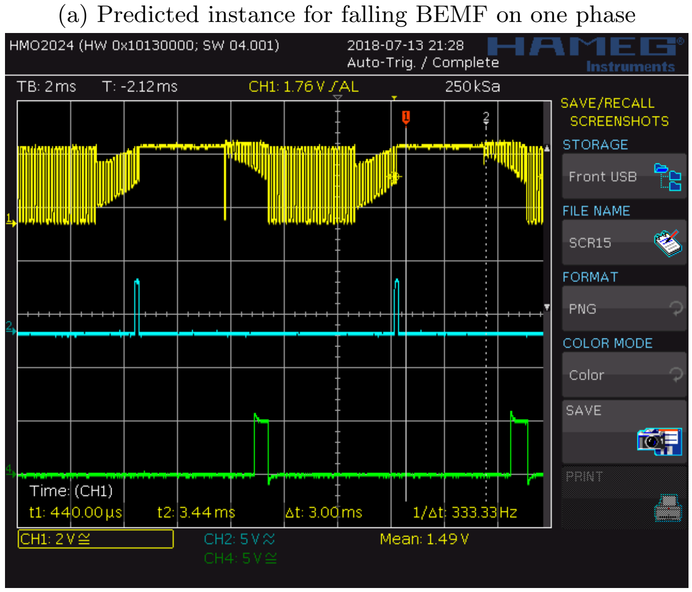


Figure 3.5: ADC measurement of BEMF on one Phase



(a) Predicted instance for falling BEMF on one phase



(b) Predicted instance for falling and rising BEMF on one phases

Chapter 4

Conclusion

It can be shown that sensorless commutation is possible with a low level Microcontroller. The capabilities of the AVR Atmega328p are sufficient to drive and measure three phases at the same time. Parameter tuning is one of the most challenging parts of this method. The start up procedure is still quite slow and thus there is a lot of improvements to be made, to make this system usable in the real world.

Bibliography

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