Block Commutation - with Digital Hall Sensors

- with Absolute Encoder

Motivation

For the proper commutation and motor operation, the rotor position information is very crucial. Only with the help of rotor position information, the electronic switches in the inverter bridge will be switched ON and OFF to ensure proper direction of current flow in respective motor coils such that the common goal of operation at a maximum torque is achieved. It is essential to have a feedback device integrated or attached to the motor shaft to indicate current rotor position to the controller.
This document gives the information about the functionality of the block commutation with the use of digital Hall sensors and with an absolute encoder based on single chip technology in combination with the Faulhaber BLDC motor.

Related / Concerned Products

All BLDC Servomotors with digital Hall sensors and absolute encoder.

Description

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field. In other words, the process of activating current flow in six directions through the appropriate motor phase windings to produce an output torque is called six-step commutation or Block commutation.

1. Block Commutation Operation with digital Hall sensors:

Rotor position can be sensed using digital Hall effect sensors embedded into the stator. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of three Hall sensor signals, the exact sequence of commutation can be determined.
Each commutation sequence has one of the windings energized to the positive power (current enters into winding), the second winding is negative power source (current exits winding) and the third is in a non-energized or in open circuit condition. The Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together.

Commutation sequence logic:

Energizing appropriate phase coils based on the Hall sensor inputs is known as commutation logic. The commutation logic specifies the coils that need to be energized for every 60° of electrical

revolution based on unique Hall sensors signals and this sequence repeats after six steps as it complete one electrical cycle. For multi-pole motors, the electrical revolutions per one mechanical revolution are multiple of pole pairs.
The following Table-1 gives the details of the motor phases switching sequence for a given Hall signal pattern to rotate in clockwise and in counterclockwise direction. The switching states „1" and „0" represent the High and Low logic level of the digital Hall sensors respectively.

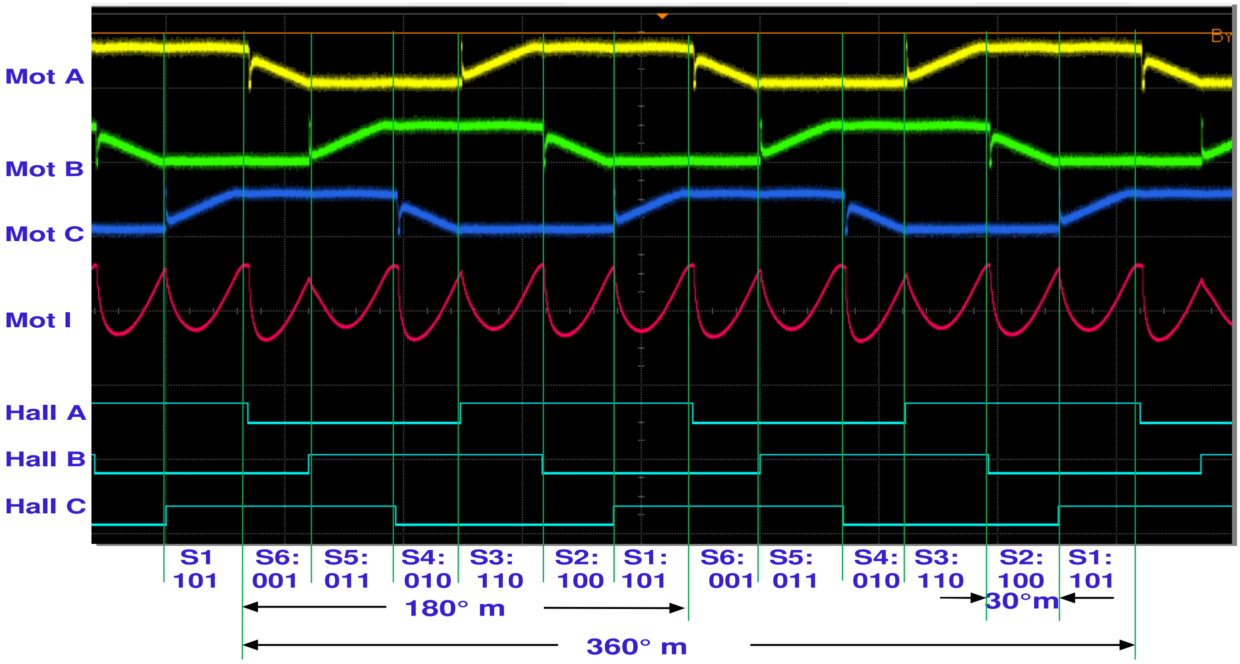

Figure 1: Block commutation sequences in clockwise direction (CW) for a 4 Pole drive

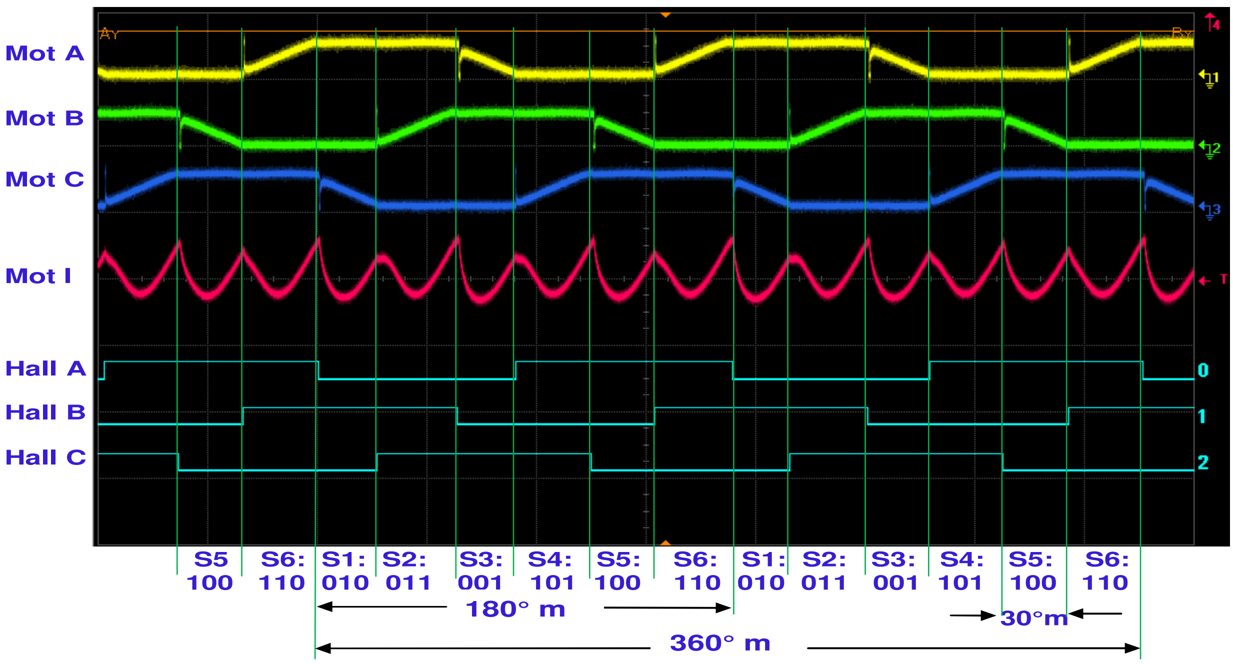

Figure 2: Block commutation sequences in counter clockwise direction (CCW) for a 4 Pole drive

Depending upon the Hall states (Hall A, Hall B, Hall C), the voltage across the motor phases changes accordingly. For instance, in the Hall state 1-0-1 in clockwise direction, the path of the current begins at the positive pin of the voltage source, flows through the phase A and B of motor windings, finally to the Ground pin. At that instance, the motor phase C remains open (marked with ‘-‘ sign in Table-1). Figure-1, shows an example of the digital Hall signals A, B and C waveforms in clockwise direction, which contain the current rotor position information used to commutate motor phases Mot A, Mot B and Mot C respectively a 4 Pole BLDC motor. From the waveform, for every 60° electrical / 30°mechanical, one of the A, B, or C Hall signals changes its logic state. Based on the A, B, C Hall states, the appropriate stator windings are energized for every 60°electrical / 30° mechanical degrees, which means there will be a total of 12 commutation states in one full rotor shaft mechanical revolution.

12 Bit Absolute Encoder (AES-4096)																					
2 poles BLDC Motor				4 poles BLDC Motor								Hall Signals			Motor Phases			Commutation States	
AES12 0…4095 (Digital Counts)		*AES12 0…359° (Mechanical Angle)*		*AES12 0…4095 (Digital Counts)*				*AES12 0…359° (Mechanical Angle)*				*Hall A*	*Hall B*	*Hall C*	*MotA*	*MotB*	*MotC*		
Start	End	Start	End	Start	End	Start	End	Start	End	Start	End								
Clockwise Direction (CW)																					
0	682	0	59,9	0	340	2048	2388	0	29,9	180	209,9	0	0	1	-	GND	Vmot	6	Step Sequence Reverse
683	1364	60	119,9	341	682	2389	2730	30	59,9	210	239,9	0	1	1	GND	-	Vmot	5	
1365	2047	120	179,9	683	1023	2731	3071	60	89,9	240	269,9	0	1	0	GND	Vmot	-	4	
2048	2730	180	239,9	1024	1364	3072	3412	90	119,9	270	299,9	1	1	0	-	Vmot	GND	3	
2731	3412	240	299,9	1365	1706	3413	3754	120	149,9	300	329,9	1	0	0	Vmot	-	GND	2	
3413	4095	300	359,9	1707	2047	3755	4095	150	179,9	330	359,9	1	0	1	Vmot	GND	-	1	
Counterclockwise Direction (CCW)																					
2047	1365	179,9	120	1023	683	3071	2731	89,9	60	269,9	240	0	1	0	Vmot	GND		1	Step Sequence Forward
1364	683	119,9	60	682	341	2730	2389	59,9	30	239,9	210	0	1	1	Vmot		GND	2	
682	0	59,9	0	340	0	2388	2048	29,9	0	209,9	180	0	0	1	-	Vmot	GND	3	
4095	3413	359,9	300	4095	3755	2047	1707	359,9	330	179,9	150	1	0	1	GND	Vmot		4	
3412	2731	299,9	240	3754	3413	1706	1365	329,9	300	149,9	120	1	0	0	GND		Vmot	5	
2730	2048	239,9	180	3412	3072	1364	1024	299,9	270	119,9	90	1	1	0	-	GND	Vmot	6	

Table-1: Block Commutation with Digital Hall sensors and absolute encoder

2. Block commutation with absolute encoder:

In combination with the FAULHABER BLDC Motors the high resolution single turn Absolute Encoders Series AES-4096 (12 Bit Resolution) can be used for precision commutation and optimized position and speed control. Using the revolutionary single chip magnetic encoder technology, the encoders can be used either for block commutation with speed controllers (e.g. SC2804S) or for sinusoidal commutation with motion controllers (e.g. MCBL 3006 S RS AES). In this section, the block commutation using the absolute encoder approach is explained.
The zero position of the encoder is adjusted to the drive winding and is always the same. Table-2 shows the Number of states per revolution, state width and counts per state for 2 and 4 pole BLDC motors. The calculations are based on the formula 1 to 3 listed below.

Pole Pairs	Number of Commutation (States/Revolution)	State Width (° mechanical)	12 Bit Absolute Encoder (Counts/State)
1	6	60	682
2	12	30	341

Table-2: Block commutation calculation with absolute encoder

$$\text{Pole Pairs x 6 (Block Commutation)} = \frac{\text{Number of States}}{\text{Revolution}} \quad [1]$$

$$\text{State Width} = \frac{360° \text{ mechanical}}{\text{Number of States per Revolution}} \quad [2]$$

$$\text{Absolute Counts Per State} = \frac{2^{\text{Absolute Encoder Resolution = 12}}}{\text{Number of State per Revolution}} \quad [3]$$

Based on the above theoretical calculations, the measurements of the commutation steps in digital counts (total range 0 to 4095) or mechanical angle (total range 0° to 359°) are carried with the 2 and 4 pole FAULHABER brushless motor drive and are given in the Table-1 as a reference. So the block commutation with an absolute encoder is determined by the zero position, the number of Commutation States and the State Width and can be easily calculated by a microcontroller.

Summary

The digital Hall sensors integrated in to the motor are used in general as position sensors for block commutation, where 6 edges per electrical revolution are available as a position. Whereas absolute encoder as an attached sensor system can be used, either for block commutation as an option to digital Hall sensors or for sinusoidal commutation with total of 4096 absolute positions are available. More precise position and speed control with the sinusoidal commutation with absolute encoder is possible.
For the more information about using the AES Interface, please refer to the Faulhaber Application Note -130.

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