Application Report

Tuning Lead Angle in DRV10x Sensorless BLDC Drivers

ABSTRACT

Brushless DC motors (BLDC) are used in various applications because of their high power density and thermal efficiency. Often systems implement sensorless BLDC control in order to reduce cost in speed control solutions. Sensorless BLDC motors come with increased complexity in control implementation. One of the complicated problems in sensorless BLDC drivers is to accurately estimate the Back-EMF (BEMF) constant and BEMF zero crossing. BEMF constant estimation is accurate only when the motor phase current is aligned with BEMF voltage. Because of the inductive effect in BLDC motors, the phase current lags phase voltage causing a difference in angle between motor phase current and BEMF voltage. Texas Instruments' DRV10x devices provide configurable lead angle feature to align the motor phase current with the BEMF voltage and also compensate for any error in the BEMF zero-crossing estimation. This application report provides steps to tune the lead angle to accurately estimate the BEMF constant and optimize efficiency by identifying the minimum current-to-speed ratio.

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1 Introduction

Lead angle, also known as Commutation control advance angle is the angle between phase voltage applied to the motor and the Motor BEMF voltage. Figure 1-1 shows the basic motor model. R and L are the resistance and inductance of the stator windings of the motor.

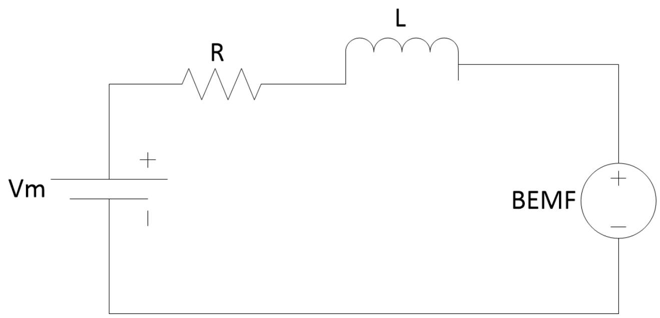

Figure 1-1. BLDC Motor model

Because of the inductance of the motor, phase current of the motor lags phase voltage applied to the motor as shown in Figure 1-2 and Figure 1-3. As a result, the BEMF voltage gets misaligned with phase current. When phase current is not aligned with BEMF voltage, the power drawn by the motor does not get fully utilized to generate torque resulting in poor power efficiency of the motor-driver system. To address this issue, DRV10x sensorless motor drivers provide configuration bits to advance the phase voltage applied to the motor and align the motor phase current with the motor BEMF voltage. Lead angle is expected to be lower for lower inductance motors and higher for inductance motors.

Phase difference between the phase to phase voltage and BEMF voltage is lead angle. In Figure 1-2, the phase current is not aligned with motor BEMF voltage. At this lead angle, the efficiency is expected to be poor. In Figure 1-3, the phase current is aligned with motor BEMF voltage by advancing the phase voltage applied to the motor. At this lead angle, the efficiency is optimized.

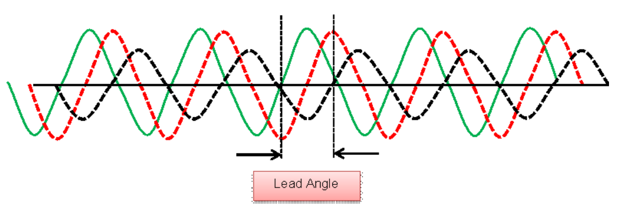

Figure 1-2. Phase current is un-aligned with BEMF voltage Lead angle is not optimized

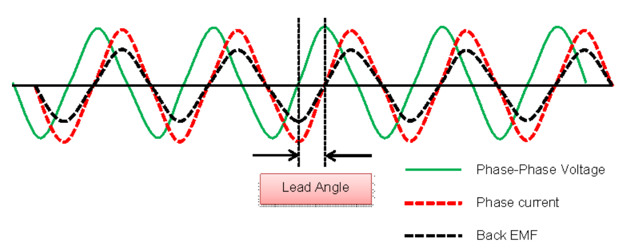

Figure 1-3. Phase current is aligned with BEMF voltage Lead angle is optimized

2 Concept

BLDC motors operate efficiently when the stator magnetic flux and rotor magnetic flux are in quadrature alignment (90°). To achieve this 90° angle between the stator and rotor flux, the BEMF voltage must be aligned with the phase current.

This alignment between the BEMF voltage and phase current can be achieved by adjusting the lead angle. It is important to know the target speed or torque of the motor because with variation in speed or torque, the BEMF voltage and phase current get misaligned for a fixed lead angle. Lead angle must be adjusted when an operating condition, such as speed and load, is changed to operate the motor at optimal efficiency. At the target speed, when the BEMF voltage and phase current are aligned, the motor draws least amount of phase current and the efficiency is optimized.

Below are the steps to tune lead angle:

1. While operating in closed loop, set the speed command to achieve the desired operating speed where the efficiency needs to be optimized.
2. Sweep the lead angle around the programmed lead angle and measure the motor phase current (rms) and motor speed (Hz) for each value of lead angle. It is recommended to measure the motor speed by measuring the frequency of FG signal for accurate results. Figure 2-1 shows the phase current and FG plot. Measure the RMS value of phase current and frequency of FG signal.

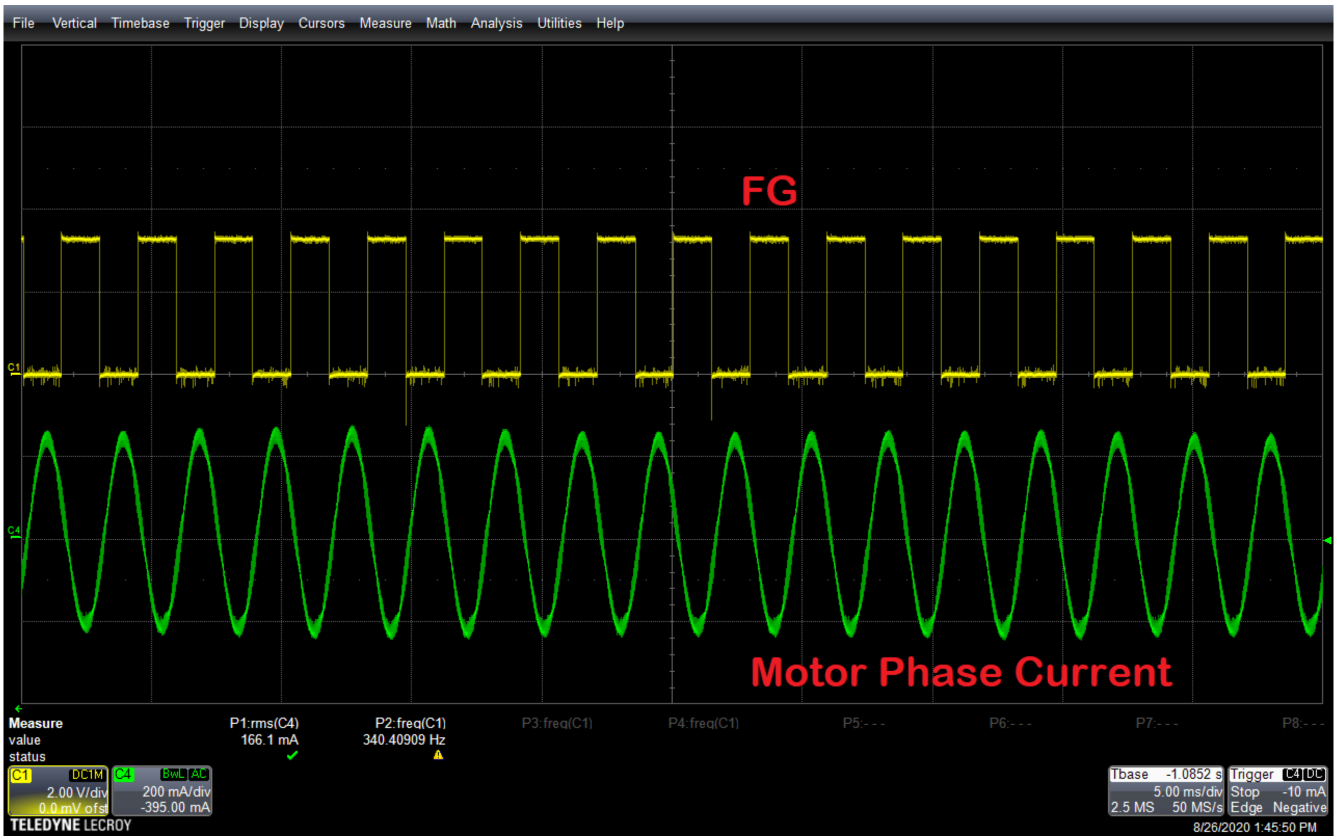

Figure 2-1. FG and Phase current

3. Calculate the ratio of phase current over motor speed. Optimum efficiency is achieved at the lead angle where the ratio of phase current over speed is lowest. At this point, the estimated BEMF will be almost equal to programmed/measured BEMF of the motor.

Here is an example of tuning lead angle for a sample BLDC motor.

Rated speed of the sample motor is 340 Hz (Electrical Speed). Speed command is set to 100% duty cycle as the efficiency needs to be optimized at 340 Hz. Table 2-1 shows the experimental phase current, speed and their ratio after sweeping the lead time from 80 µs to 400 µs. DRV10x takes lead time as input and converts lead time to lead angle. Data points in Table 2-1 are plotted in Figure 2-2. Figure 2-2 shows the current-speed ratio Vs Lead time.

Table 2-1. Experimental phase Current, Speed, and Current/Speed Ratio with different Lead times

Lead time (µs)	Phase current (mA)	Speed (Hz)	Phase current/Speed (mA/Hz)
80	326.6	301.3	1.084
100	324.2	301.2	1.076
120	325.4	301.2	1.080
130	326.7	301.4	1.084
140	325.5	302.3	1.077
150	319.1	303.1	1.053
170	317.0	302.2	1.049
200	310.5	305	1.018
220	302.4	306	0.988
240	260.2	315.6	0.824
260	250.3	318	0.787
280	235.6	322	0.732
300	191.0	335.9	0.569
320	166.1	340	0.489
360	237.7	398	0.597
400	251.0	403	0.623

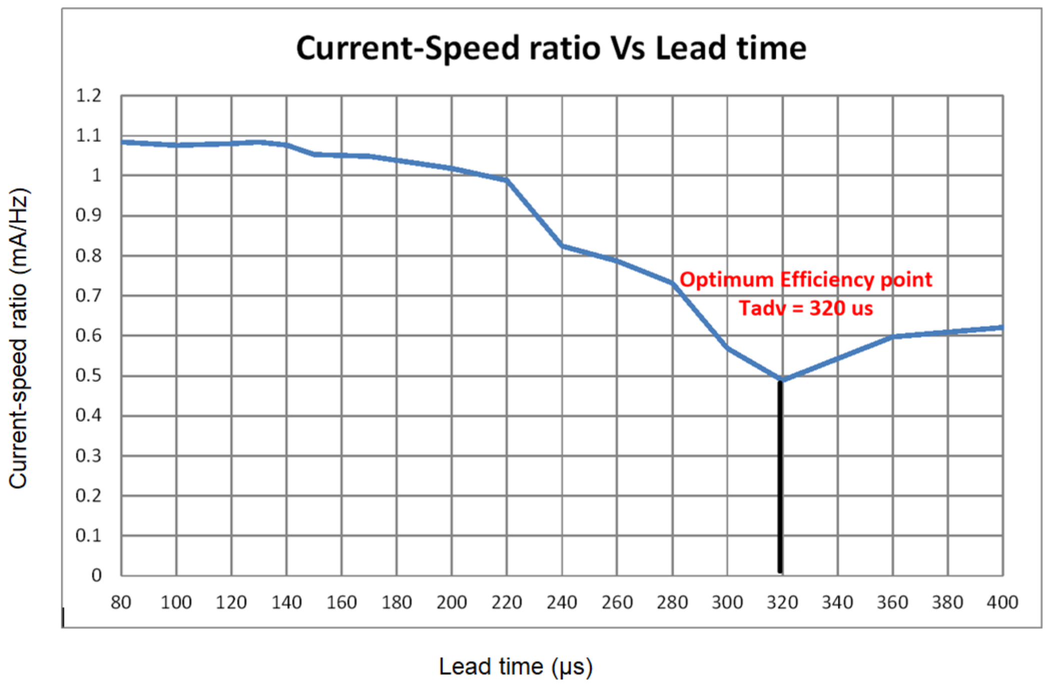

Figure 2-2. Current-Speed ratio Vs Lead time

The lowest current-speed ratio is achieved at 320 µs. At this operating point, minimum load current is drawn by the motor. This will be the optimum efficiency point at 340 Hz. Above 320 us we see the speed and phase current increasing rapidly. This is because the motor is in the field weakening region where the rotor magnetic flux gets weakened with increase in phase current and motor speed increases above the rated speed. It is not recommended to operate DRV10x devices in field weakening region for applications sensitive to acoustic noise because the phase current might be distorted and can also reduce the life span of the motor.

3 References

For additional references, refer to the following.

- Texas Instruments, Adaptive Drive Angle Adjust
- Texas Instruments, DRV10987 Tuning Guide
- Texas Instruments, DRV10974 Tuning Guide