INNOVATION WITH PURPOSE

INNOVATIVE MOTOR CONTROL: SETTING A NEW STANDARD FOR BLDC MOTOR DRIVE TECHNOLOGY

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Brushless DC [BLDC] motor control has been gaining traction across all markets, replacing DC and stepper motors. The primary driver is the demand for increased efficiency and lower noise. Just a decade ago, BLDC motors used in systems that required high performance also required software-based microcontrollers to create efficient and quiet commutation. Today Allegro offers solutions with embedded commutation, bringing low noise and efficient drive with no microcontroller or custom software. Allegro's sensorless sinusoidal BLDC motor drivers set a new standard in quiet and efficient drive and deliver them in a simple single package solution with no programming required.

INTRODUCTION

Even though the fundamentals of BLDC motor control remain constant, BLDC motor characteristics vary widely across applications. For example, a server fan requires a high speed in excess of 30k rpm and server suppliers want to capitalize on incremental cost savings by being more efficient than their competitors when scaled to thousands of individual fans. In contrast, a personal computer fan requires a lower speed and needs to be exceptionally quiet when starting and running so as not to disturb a studying student.

Addressing differing requirements may be the biggest challenge in developing motion control algorithms. Allegro meets this challenge with solutions that integrate the motor control algorithm. By embedding the motor commutation algorithm in hardware, the customer only needs to select the parameters for startup and running conditions with a simple-to-use graphical user interface (GUI). These parameters are stored in the on-chip EEPROM and are used by the hardware-based algorithm. There is no programming required, reducing overall development resources significantly. With one device, multiple motors for different applications can share the same hardware, reducing the burden on software teams while simplifying and reducing development time. This paper will focus on the basics of the sensorless control algorithm, the advantages of different sensing techniques, and how the GUI can drive a full-featured sensorless sinusoidal BLDC motor with no software programming required.

BASICS OF SENSORLESS BLDC CONTROL

In order to drive a BLDC motor, the position of the rotor must be known. This is often accomplished with either Hall sensors or encoders. However, when these types of sensors are used to drive a BLDC motor, the circuits can become very complex and expensive. A way to reduce complexity and cost is to enable sensorless technology. When operating without physical sensors, the position of the rotor is determined by a circuit called the "position observer" which looks at a different property of the motor called Back Electromotive Force or BEMF.

When the BLDC motor is spinning, the relative motion between the windings (stator) and the magnetic field (rotor) produces BEMF, which is the same property that allows a motor to act as a generator. There are two methodologies for measuring BEMF, Windowed (BEMF observed) and Windowless (BEMF calculated). And with this information the observer can estimate the rotor position to control motor rotation.

WINDOWED VERSUS WINDOWLESS POSITION OBSERVER

The three-phase BLDC motor has three windings (or phases). In a trapezoidal drive, for example, two of the three phases are driven with current and the third is left undriven. The undriven phase is also called floating phase. BEMF will be induced on the floating phase, which implies the rotor position information.

By measuring the BEMF voltage (analog-to-digital converter (ADC) or voltage comparator) to the floating phase, that phase can be used as a "sensor" to measure the rotor position.

See Figure 1.

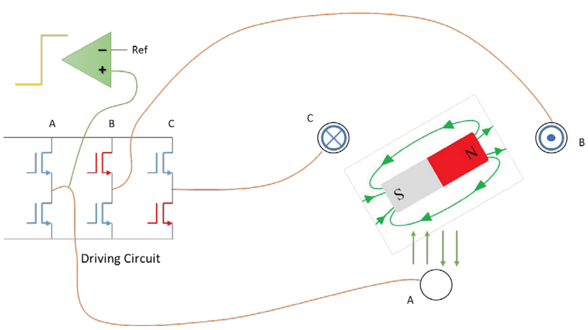


Figure 1.

This is the "direct" or observed way of measuring BEMF. The floating phase is required, and the phase must be undriven during measurement.

In three-phase sinusoidal drive, current is flowing in all three windings making meassurment of BEMF difficult. One method to observe BEMF in sinusoidal drive is to have an electrical observation "window," ***Figure 2***, while driving the motor enabling this direct BEMF measurement method.

$$\begin{bmatrix} u_{UN} \\ u_{VN} \\ u_{WN} \end{bmatrix} = \begin{bmatrix} R_S & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_S \end{bmatrix} \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} + \begin{bmatrix} L_{UU} & L_{VU} & L_{WU} \\ L_{UV} & L_{VV} & L_{WV} \\ L_{UW} & L_{VW} & L_{WW} \end{bmatrix} p \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} + \begin{bmatrix} e_U \\ e_V \\ e_W \end{bmatrix}$$

As digital densities have increased and processing techniques have advanced the "windowless," ***Figure 3***, method becomes possible. The "windowless" method is based on the "indirect" or calculated measurement of BEMF.

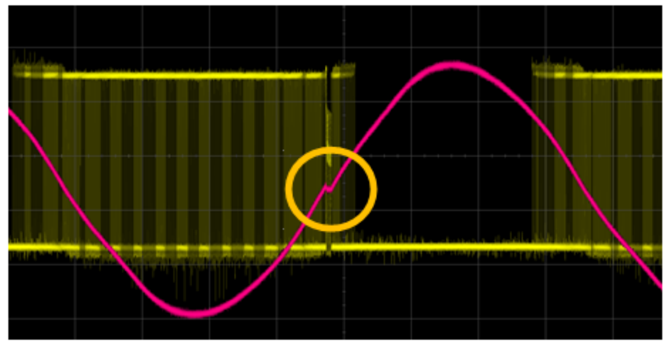


Figure 2 - Windowed.

The windowed method is simpler than the windowless method, requiring less hardwire resources (ADC) and less calculation. The windowed method is also immune to the motor parameter drifts, but operates at lower motor speeds.

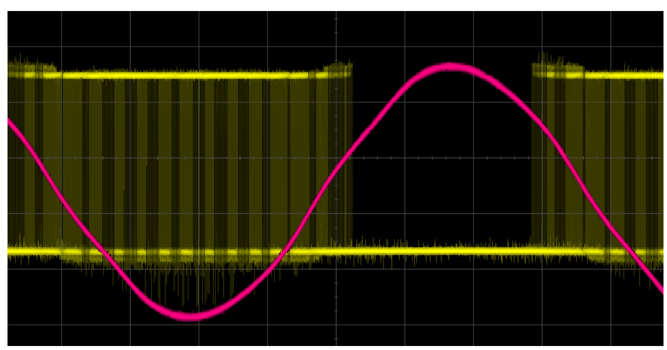


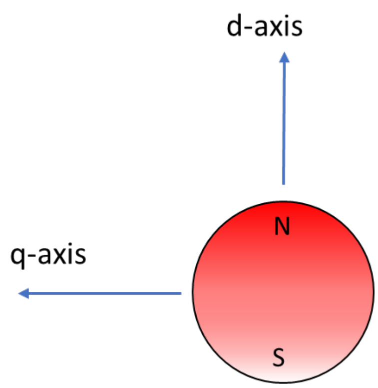
Figure 3 - Windowless.

The windowless method gets rid of the "observation window", reducing the acoustic noise by maintaining continuous current in all windings.

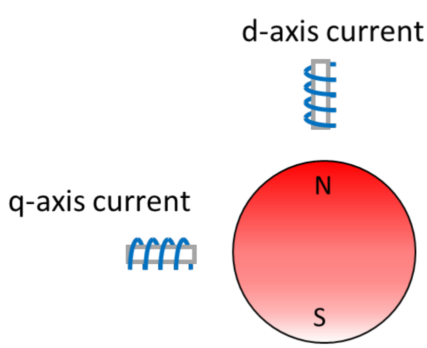
IMPROVE EFFICIENCY WITH PHASE ADVANCE

In order to understand phase advance it is necessary to have a simplified frame of reference. By using the Direct-quadrature-zero transform, or dq transform, we can take the rotating reference frame of a three-element vector to produce three DC signals which are easier to perform calculations with.

In the transform, the motor variables voltage, current, and magnetic flux are transferred to the dq coordinate. D-axis is the direction when magnetic flux reaches its maximum, and Q-axis is 90 degrees from the D-axis.



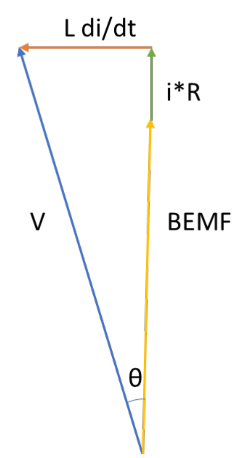
The motor current, as a vector, contains both d-axis and the q-axis elements. The d-axis current (id) is the current that produces the inductive flux in the d-axis direction and the q-axis current (iq) is the current that produces the inductive flux in the q-axis direction.



The q-axis current generates q-axis inductive flux, which interacts with the permanent magnetic flux (centered in d-axis) to generate torque on the rotor causing it to spin.

The d-axis current does not generate rotational torque. As the inductive flux generated by the current is parallel to the magnetic flux, it can produce zero force. As a result, d-axis current is realized as heat generated from i2R losses; this results in direct loss of efficiency. To optimize the efficiency, the current vector would ideally be controlled such that id is equal to zero. With current in the d-axis equal to zero, all the current resides in on the q axis. The result is a vector most suited to generating inductive flux, and therefore mechanical torque.

The technique to bring the d-axis current to zero is called phase advance. Because motor winding is an inductive circuit, the phase voltage will lead the phase current. To maintain maximum efficiency phase advance is used to align the phase current to the BEMF by advancing the phase voltage by angle **θ**.



Allegro Microsystems' motor drivers use an integrated phase advance algorithm to dynamically change the lead angle in order to maximize efficiency over all operating conditions.

Note: The concept of id equal to zero is only true for an ideal motor model. In the real world there are second order effects caused by interaction of the permanent magnet and the iron in the motor which generates detent torque. To negate the detent force there should be some small amount of current in the d-axis which relates to the lead angle. Allegro's phase advance algorithm takes into account the total effects in the system and adjusts the lead angle to provide highest operating efficiency.

A FLEXIBLE SOLUTION WITHOUT SOFTWARE

More demanding customer requirements have created a shift in motion control design that favors flexibility and improved time to market. Using Allegro's hardware-based algorithm, the solution is "plug-in and spin", eliminating the cycle of software development and debug and significantly reducing time to market. Flexibility is achieved by implementing a simple to use Graphical User Interface (GUI). Now, high performance and full-featured sensorless control is just a few mouse-clicks away.

Briefly, the functions included in the GUI, Figure 4, that makes sensorless control so easy are described below.

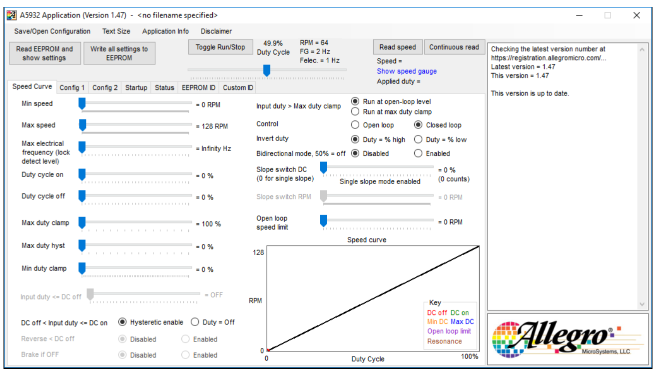


Figure 4 – Allegro GUI Software A5932

SELECTION OF PARAMETERS

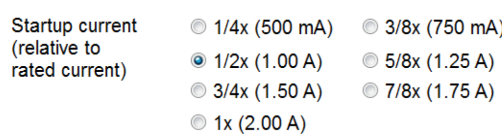
The greatest challenge for sensorless BLDC control is at startup, because BEMF is proportional to the motor speed. Allegro's GUI software addresses this challenge for all motor types by providing configurability for key parameters that govern how the motor starts up.

At startup, when motor speed is low or zero rpm, the BEMF is small and hidden by measurement noise. One way to generate BEMF is to control the motor in open loop until the speed is able to generate enough BEMF to be detected. However, when an open loop startup method is used, the alignment of the rotor to the stator can cause the rotor to move slightly either forward or reverse, and the rotor can oscillate slightly before it comes to rest due to the inertia of the load.

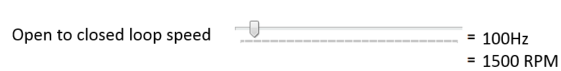
Initial position detection (IPD) is one way to prevent this. Allegro's intelligent algorithm can detect initial motor position by injecting high-frequency pulses before the rotor is spinning. This is useful for fan-type motors which have exposed blades. Even though IPD does not cause the rotor to move initially, the process of high-frequency injection can cause acoustic noise in some motor designs. Those applications that require extremely quiet operation may want to disable the IPD. This is a configurable option in Allegro's GUI.

Motor startup acceleration rate must be adjustable to optimize for different loads. Based on Newton's second law, F = ma, or T = J × β in the rotational system (where T is the driving torque, J is the load inertia, and β is the acceleration rate), there is a maximum β to ensure a successful startup, which is βMAX = TMAX / J. Without the adjustable acceleration parameter, the startup either takes too long or has the risk of failure.

The startup current parameter determines the maximum torque. Higher startup current can potentially improve startup time, but it also causes startup acoustic noise.



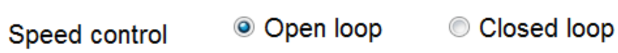
After pulling the motor to a certain speed, the BEMF measurement or estimation method will be used, then the system will go to closed loop. Set the threshold as low as possible so that the motor will run quickly under an efficient closed-loop condition. However, it is not reliable to go to closed loop if the motor BEMF is low—the transition will fail and the motor will be stuck. Therefore, the open-to-closed loop threshold parameter must be set. Typically, one tenth of the full speed is recommended, depending on motor parameters.



INTEGRATED CLOSED LOOP SPEED CONTROL

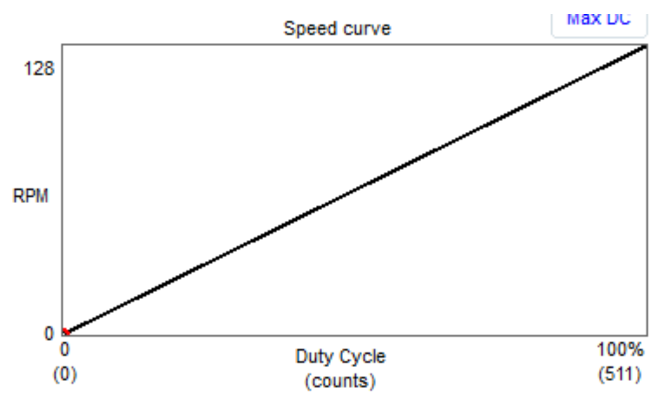
Applications require different speed control methods, so it is important to have a flexible GUI that allows for speed control configuration.

The first speed control option in Allegro's GUI is speed open loop or speed closed loop. Speed open loop is like the "gas pedal" of a car—it controls the speed but doesn't directly relate the speed to the depth of pedal pressure. Ramping up a hill or heavy load will slow down the car even when the same amount of pedal pressure is given. The closed loop mode is like "navigation" mode—speed will be locked to a reference and the power is adjusted based on road conditions.



The next option is speed input mode. Normally, analog mode, PWM mode, or CLOCK mode are provided. For analog mode, speed demand is analog voltage. For PWM mode, PWM duty determines the speed demand. For CLOCK mode, the frequency of the input signal determines the speed.

Also, speed curves are provided to meet different application requirements.



CONCLUSION

We can see the market changing from traditional stepper and DC motor control to BLDC motors. At the same time, BLDC drive is becoming increasingly complex to develop and deliver solutions that meet customer and/or application requirements. Removing the complexity from BLDC drive allows all system designers to develop solutions that are easy to set up and validate while providing all the benefits of sensorless sinusoidal BLDC control.

Allegro MicroSystems sensorless BLDC drive solutions are unique in the market, providing industry-leading noise performance in a small, efficient footprint with no software programming.

Sources

[1] James P. Johnson M. Ehsani Yilcan Giizelgiinler, "Review of Sensorless Methods for Brushless DC", Conference Record of the 1999 IEEE Industry Applications Conference. Thirty-Forth IAS Annual Meeting (Cat. No.99CH36370) Year: 1999, Volume: 1 Pages: 143 – 150

[2] N. Matsui, "Sensorless PM Brushless DC Motor Drives," IEEE Trans. on Industrial Electronics, vol. 43, no. 2, pp. 300-308, 1996

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