Technical Article

How improved magnetic sensing technology can increase torque in BLDC motors

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Across a range of automotive and industrial applications, brushless DC (BLDC) motors (also known as electronically commutated motors) offer many advantages over other types of DC motor, and are now very widely used.

In a standard motor control circuit, speed regulation, acceleration and position control are normal, well understood functions. But in BLDC motor control systems it is also possible, through use of an intelligent magnetic Hall position sensor, to implement precise control of torque at start-up and in high-speed operation. Effective torque control provides for more efficient operation and eliminates juddering and other unwanted mechanical effects that are caused by torque ripple.

This article describes an important development in the implementation of magnetic sensing which brings even more refined control of torque at high speeds.

BLDC motor basics

BLDC motors consist of a rotating permanent magnet (rotor) and three or more equally spaced fixed windings (stators). By controlling the currents in the stators, a magnetic field of arbitrary direction and magnitude can be produced. Torque is the result of the forces of attraction and repulsion be-tween the rotor and the stator field acting on the rotor shaft.

The angle at which force is applied to the rotor field affects the amount of torque produced (see Figure 1). To produce the most torque, the stator field must be orthogonal to the rotor field. This in turn means that the position of the rotor relative to the stators is a crucial piece of data in a BLDC motor control system.
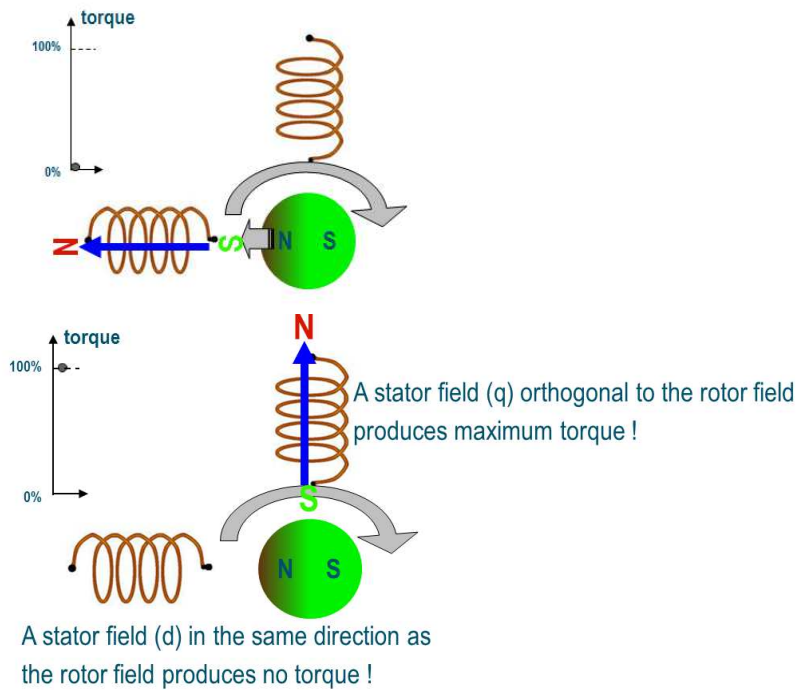
A stator field (q) orthogonal to the rotor field produces maximum torque !

A stator field (d) in the same direction as the rotor field produces no torque !

Fig. 1: the stator field should be orthogonal to the rotor field for maximum torque

Methods for sensing position of rotor shaft

In a BLDC motor, there are several methods to measure the position of the rotor shaft. One commonly implemented method is sensorless back EMF (back Electro-Motive Force) position sensing, using a Wye or Delta winding and/or the stator coil current. Unfortunately, this method is unsatisfactory because the position measurements it produces are imprecise, resulting in large torque ripple. Back EMF sensing also produces weak torque at start-up. Back EMF is not even particularly easy to implement, since it requires an additional algorithm to calculate the absolute position of the rotor, as well as the relative position data.

Motor control system designers have also used various methods for rotor shaft position sensing using sensors. This includes optical sensing, in which position data are derived by decoding alternating patches of light and dark on a rotating code wheel; and the use of discrete magnetic Hall switches. Resolvers may also be used, flanged on to the rotor shaft.

Optical sensors, however, are bulky and vulnerable to contamination by dust, grease and dirt. Simple Hall switch arrays (see Figure 2) produce crude, low-resolution position data outputs which

compromise the motor's efficiency and produce high levels of torque ripple. Resolvers are large and expensive.
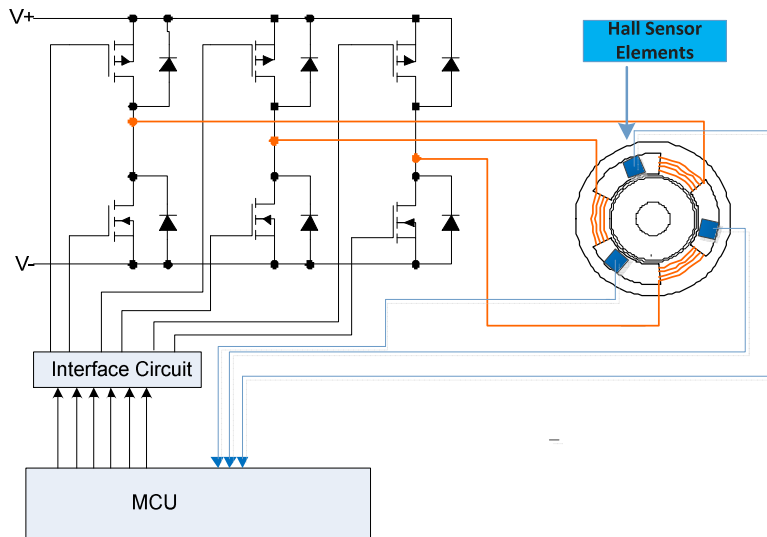

Fig. 2: typical application circuit for position sensing using discrete Hall switches

A newer device type, the magnetic position sensor IC, contains integrated Hall sensors, and is mounted on the end of the shaft. A magnetic position sensor such as the AS5132 from ams, paired with a simple two-pole magnet mounted on the end of the shaft, resolves the position of the shaft. The continuous changes in the magnetic field produced by rotation are represented by a digital output via a serial interface, as well as decoded position information (UVW co-ordinates).

Unlike an array of discrete Hall switches, a magnetic position sensor with integrated Hall sensors produces precise, high-resolution position data. It also maintains high accuracy at low speed and when the rotor shaft is stationary. And unlike an optical position sensor, a magnetic position sensor is immune to contamination and occupies little space.

Implementing a magnetic position sensor in practice

The trend in automotive and industrial applications is to place the control circuit close to the motor. In some applications, the designer will choose to implement the decoding algorithms in an embedded microcontroller (MCU) dedicated to BLDC commutation, which must be placed close to the sensor. Here, all components are mounted on the same PCB, and the MCU uses the ABIndex* output from the magnetic position sensor (see Figure 3).
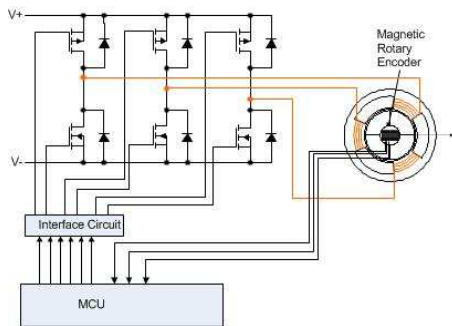
Fig. 3: simple schematic of a BLDC motor control circuit which implements position sensing through a magnetic position sensor

This approach provides very good resolution at start-up: the MCU can derive absolute position data from the sensor via the Synchronous Serial Interface (SSI). The MCU can also perform dynamic adjustment to the configuration, providing the designer with greater flexibility. The main disadvantage of this approach is that it requires another MCU in addition to the main system controller or Engine Control Unit (ECU).

The alternative approach is to interface the magnetic position sensor directly to the main system controller or ECU, thus eliminating the space and cost required for a dedicated MCU for BLDC motor commutation. In this topology, the magnetic position sensor must supply both ABIndex and UVW data to the controller.

The main drawback of this approach is that it sacrifices the opportunity to maximise torque, because it does not produce absolute position data at start-up.

Using either of these approaches, however, the motor control designer gains a high-resolution signal. This enables the controller to switch a precisely regulated current through the stators to deliver a magnetic field which is constantly orthogonal to the rotor. Torque may be maximised, and torque ripple can be all but eliminated. The complete solution – IC and two-pole magnet – is small and easily assembled on the end of the rotor shaft.

New enhancement improves accuracy at high speed

Previous generations of magnetic position sensors have, however, suffered from one drawback: the position sensor takes time to calculate the angle based on the magnetic field data sensed by the integrated Hall elements in the IC. This time, or propagation delay, causes an error which is larger the faster the rotor turns (see Figure 4). If this error is not corrected, the controller's signals to the stator windings will generate a magnetic field which is not orthogonal to the rotor, leading to a reduction in torque and a loss of efficiency.
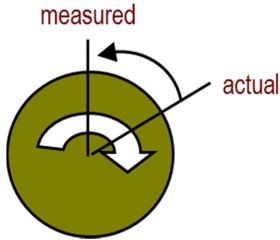
Fig. 4: propagation delay means that the measured angle is different from the actual angle

Users of magnetic position sensors have sought to reduce the error by offsetting the measured angle, using a calculation performed in the MCU or ECU to determine the size of the offset. Now ams has introduced a new device, the AS5132, which makes it possible to implement an offset directly in the sensing IC itself without any overhead on the MCU/ECU.

Figure 5 shows the angle error in the output of three different position sensors available to buy today; each causes a different propagation delay. (The AS5132 has a propagation delay of 20μs.)
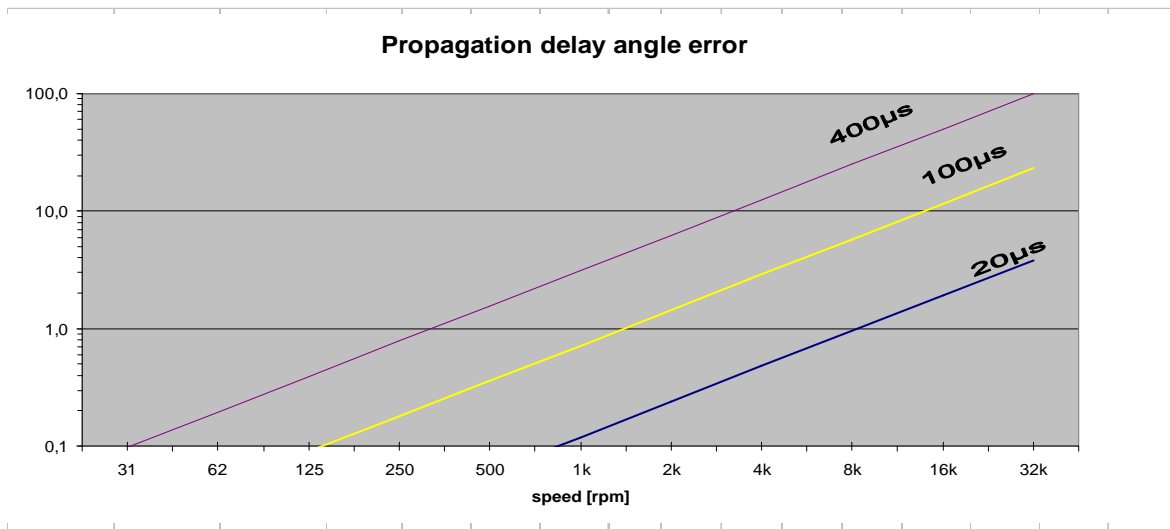

Fig. 5: angle error attributable to propagation delays of various durations

The angle error increases in a linear relation to speed. A sensor with 400μs propagation delay has an error of 1° @ ~300rpm. A sensor with 20μs propagation delay has an error of 1° @ 8,000rpm.

The approach ams has developed is to add a speed-dependent offset to the measured angle.

In the case of the AS5132 , at a speed of more than 8,000rpm the error is >1°. By adding a zero offset of 1°, the error is corrected to 0° at 8,000rpm (see Figure 6).
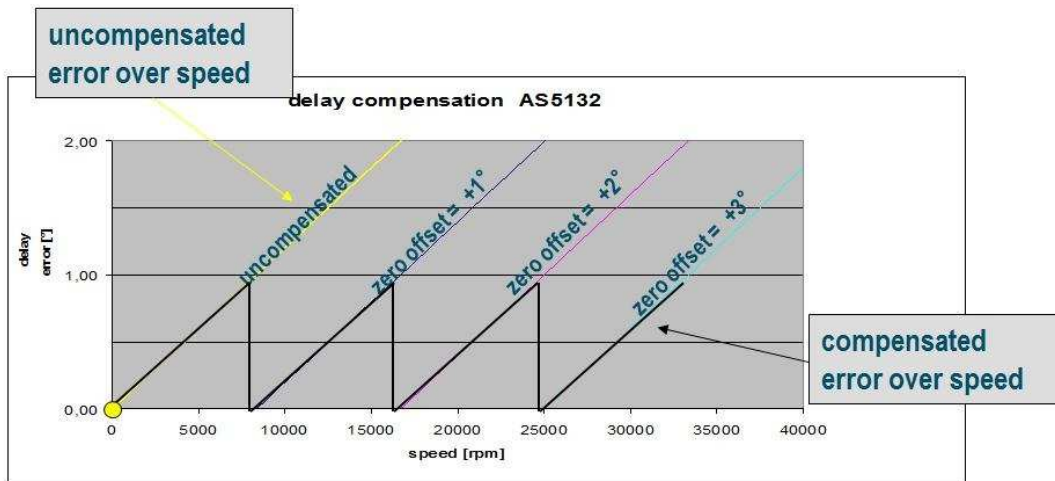

Fig. 6: the operation of offset error compensation in the AS5132

This zero offset can be implemented easily either by programming a microcontroller or directly in the position sensor IC.

Implementing pre-commutation error compensation in the AS5132

Error compensation can be implemented either through static pre-commutation or dynamic pre-commutation. Figure 7 shows the principle of pre-commutation in the AS5132. This example is for a two-pole pair configuration and static pre-commutation offset by 1°. The upper diagram shows the correct position and the measured position of the UVW signals with a 1° error at high speed. The lower diagrams show how the error is compensated through pre-commutation in both directions.
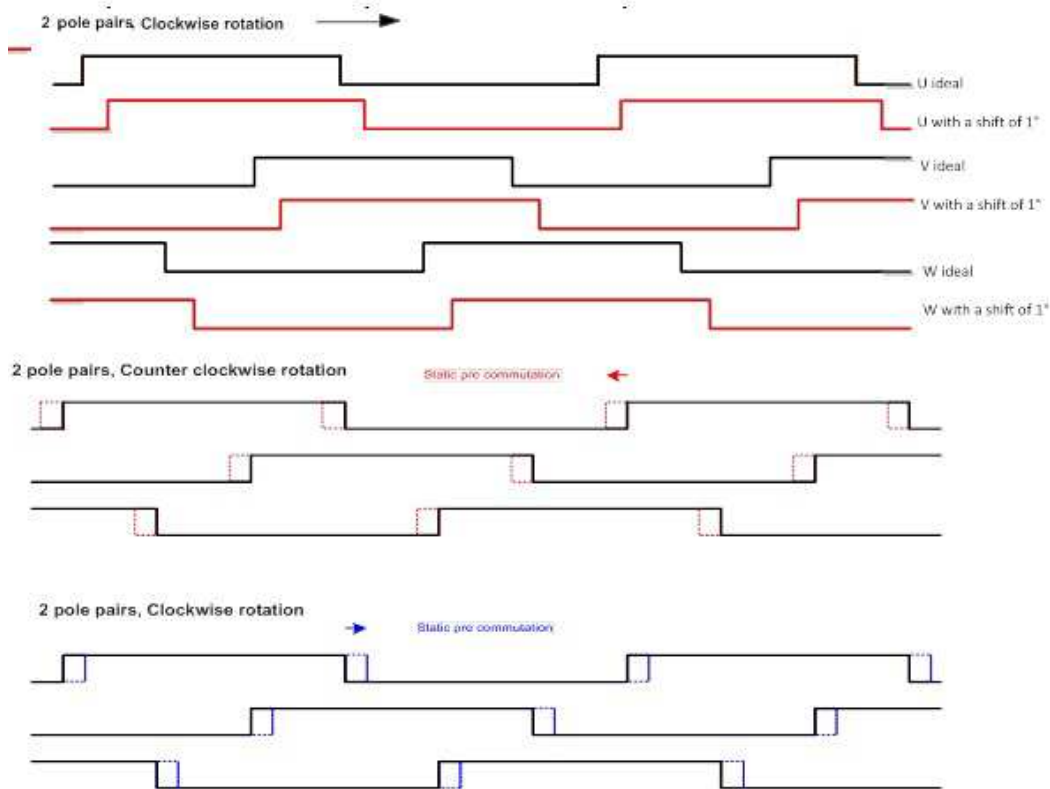
Fig. 7: error compensation achieved through static pre-commutation (1° offset)

If the motor has a single operating setting – and in particular torque and speed are constant – the AS5132 can implement static pre-commutation by programming its integrated OTP memory block. It is possible to set a shift of 0°, 2°, 4°, 7°, 8°, 10° or 12° (mechanical angle). Once programmed, the offset cannot be changed.

In the event of a change of direction, static pre-commutation is always enabled and changes automatically the value of the output.

If the speed and load are variable, the AS5132 can instead implement dynamic pre-commutation. With an instruction from the ECU/MCU via the SSI interface, the AS5132 can shift by up to 60° to the point at which torque is maximised. This dynamic value will be stored in the interface register and will be set to zero automatically if there is a change in direction or if the motor stops (see Figure

8). This is important if there is a difference in speed and load between clockwise and counter-clockwise rotation.
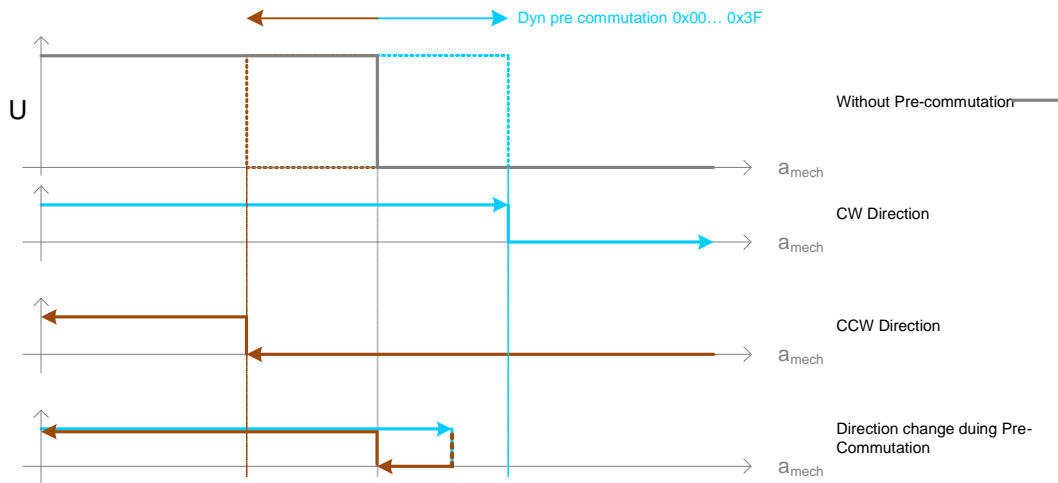

Fig. 8: operation of dynamic pre-commutation in the AS5132 magnetic position sensor IC

Conclusion

Magnetic position sensors provide designers of industrial and automotive BLDC motors with a small, robust and easily assembled position sensing solution. The new AS5132 from ams improves on previous generations of magnetic position sensor by compensating for the angle error attributable to propagation delay, which is most noticeable at high speeds. ams has taken particular care to ensure that the pre-commutation error-compensation techniques available in the AS5132 are very easy to programme, and do not require software routines to be executed in a host microcontroller or ECU. As a result, BLDC motor manufacturers can benefit from very accurate position data and consequently high levels of torque even in high-speed applications while gaining the benefits of using a magnetic position sensor.

* ABIndex are incremental outputs: signals A and B are quadrature signals 90° apart, and signal I is a reference mark. This mark represents the programmed zero position.

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