New Sensor Developments Drive BLDC Motor Control Performance

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The Move to BLDC Motors

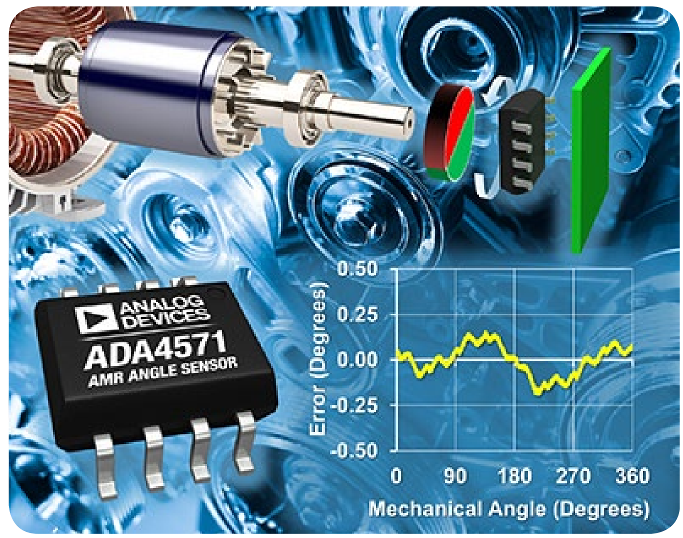
In recent years, there has been a significant move to replace ac motors or mechanical pumps with high efficiency, brushless direct current motors (BLDC) in many end markets and applications. Some of the key benefits of using BLDC motors include: higher power and thermal efficiency, improved space/weight efficiency, higher reliability (brushless), and safer to operate in dangerous environments (no brush dust or sparks generated, as in brushed motors). In addition, given that BLDC motors are commutated electronically, it's easier to control torque and speed parameters throughout the speed range of the application, as well as gain more complex control, like maintaining a holding torque or speed limitation. Because of these benefits, BLDC motors are making their way into a host of existing and new applications. In the automotive sector, BLDC motors have been used to replace hydraulic actuators and brushed motors in order to reduce weight/size, extend operating life, lower maintenance cost, and boost overall system performance and efficiency. With the automotive industry driving toward optimum fuel efficiency, BLDC motors enable on-demand performance and help to reduce engine load in powertrain, power steering, and HVAC (heating, ventilation, and air conditioning) systems, in addition to starter motors/generators and multiple variations of pumps (water/fuel/oil).

The Role of Angle Sensors in BLDC Motor Control

For accurate control and high efficiency commutation of the motor, high resolution current and rotary position information is critical. In a typical resolver-based system, the resolution and accuracy can be very high, but the end solution can be expensive and bulky, due to the physical footprint of the resolver itself. A sensorless approach can also be used to sense back EMF currents, reducing sensor weight and cost, but motor start-up performance can be problematic because there is no back EMF generated and thus no position data available. Other solutions, such as utilizing three Hall effect sensors to detect the position of the motor's magnets, are often used in cost sensitive applications. In this case, resolution is achieved, and three signals need to be monitored. In addition, the sensors are not collocated, leading to potential space and mounting challenges.

An alternative approach is to use an inexpensive, yet precise, angle sensor based on anisotropic magnetoresistive (AMR) technology. With an AMR sensor, high angular accuracy is achieved, and a single sensing element can be integrated with the electronic circuit in the same package. This makes it possible to realize a very small sensor subsystem and offers opportunities for positioning the sensor within the motor assembly.

Analog Devices has partnered with the leader in MR technology, Sensitec GMBH, to offer the ADA4571, which integrates a high precision AMR sensor with a high performance instrumentation amplifier in a single package.



With a production tested maximum angular inaccuracy of 0.5° over the extended operating temperature range of −40°C to +150°C, built-in diagnostics, large output levels, EMC protection, and low offset drift, the ADA4571 is an ideal sensor to realize high performance BLDC motor control with speeds in excess of 25,000 RPM.

AMR Technology

A sensor based on the AMR principle is one where the material resistivity depends on the orientation of magnetization with respect to the direction of the current. The sensor is typically deposited as a thin film permalloy (a magnetic iron-nickel alloy). An AMR sensor operates in magnetic saturation, and thus the contribution of the external magnetic field dominates the resistance change. The resistance is a maximum when the external field and current direction are parallel and a minimum when the applied field is perpendicular to the plane of the current carrying permalloy. A simplified picture of how an AMR sensor works can be seen in Figure 1.

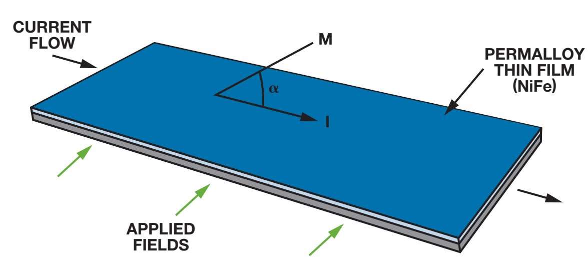


Figure 1. AMR principle.

With two independent Wheatstone bridge configurations arranged at 45° from one another, an angular sensor can be realized whose sine and cosine outputs are dependent on the external field direction. This configuration provides a sensor with a 180° absolute measurement range.

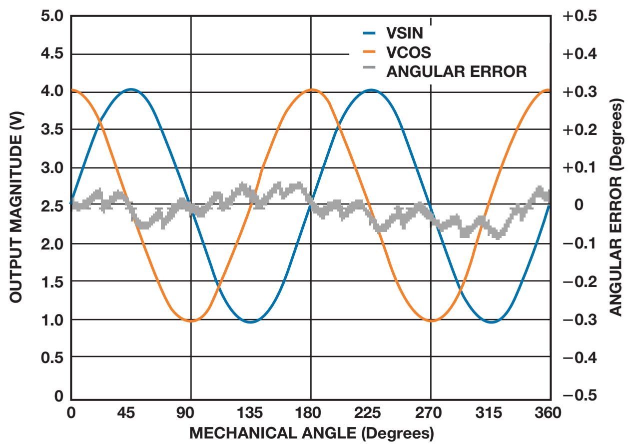


Figure 2. ADA4571 error (grey) and output waveforms (orange/blue) over a 360° mechanical rotation.

Figure 2 shows the typical high output levels and angular error from the ADA4571 when a rotating magnetic field is applied over a 360° mechanical rotation. Typical errors are less than 0.1° after an offset correction and an arctan calculation is performed in a host microcontroller.

Sensor Mounting

With most BLDC control systems, there are a number of options to configure and mount the sensor depending on available footprint and accessibility of the shaft. Two configuration examples with the ADA4571 are shown in Figure 3.

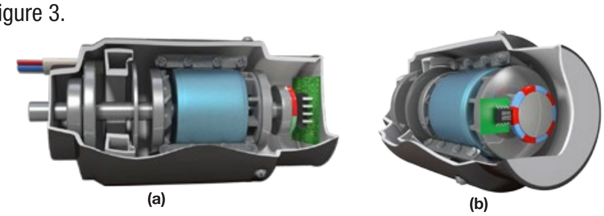


Figure 3. BLDC systems with ADA4571 (a) end of shaft system (b) off-axis system.

A typical end of shaft configuration includes a diametrically magnetized disc magnet mounted to a rotating shaft, such as inside the motor assembly shown in Figure 3 (a). The magnet provides a magnetic field that passes through the plane of the sensor.

In this configuration, a direct rotor angle reading is realized without contact between the mechanical and electrical components. As AMR technology is not dependent on the field strength, it is tolerant to variations in the air gap. The independence of the field strength also eases mechanical tolerances and material selection of the magnet materials.

The compact end of shaft configuration means the sensor can be mounted directly onto a printed circuit board (PCB) in close proximity with the electronic controls (microcontroller, MOSFET), minimizing signal routing and proximity to the harsh motor environment.

A second possible configuration is off-axis as depicted in Figure 3 (b). An off-axis configuration can be used in applications where the shaft, to be sensed, cannot be terminated with a magnet. In this configuration, a pole ring provides the stimulus, and the sensor and pole ring can be mounted anywhere along the shaft. Typical applications include electric power steering pumps or BLDC motors where the shaft end is not available due to space constraints.

Given the low latency and accurate position feedback information from the ADA4571, the motor phase's currents can be carefully controlled to provide a smooth motor response to dynamic loads, or to maintain a constant speed under variable conditions. The end result is better control, maximum torque, improved efficiency at startup/stall, and better running conditions.

Sensor Setup and Calibration

For enhanced accuracy, a number of calibration routines can be performed at the user's end of the line. A one time offset calibration can be performed to eliminate the initial offset of the sine and cosine signals.

Figure 4 shows typical performance after a one time offset calibration at room temperature.

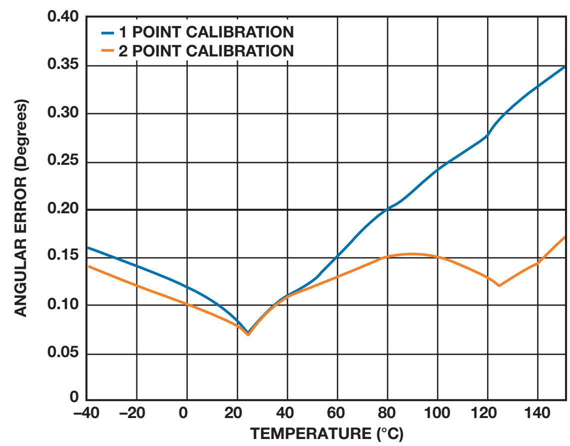


Figure 4. Typical angular error over temperature for 1-point and 2-point correction.

Due to the offset drift of the sensor, angular accuracy may degrade over temperature as seen for the single point calibration case at 150°C. Performance can be improved with a 2-point temperature calibration. In this case, the offset can be interpolated with information from the on-chip temperature sensor and compensate for offset changes over temperature.

BLDC systems in free running applications can take advantage of continuous offset correction techniques by averaging the sensor outputs over a specified time. Dynamic offset compensation in the microcontroller can achieve very high accuracy across temperature and operating life.

Unlike other sensor technologies (Hall/GMR/TMR), the ADA4571 does not need additional calibration steps, such as amplitude correction or orthogonality correction. Amplitude mismatch is production guaranteed to be less than 1%, and orthongonality is guaranteed by the advanced sensor design. The sensor also exhibits negligible hysteresis, which enables highly reliable and accurate position information.

For lower performance and cost sensitive applications where high accuracy is not required, the ADA4571 can be used without any end of line offset correction. In this case, the ADA4571 is guaranteed to have less than 5° of angular error. This can be useful in some uncalibrated applications, as the host controller can optimize start conditions knowing the position of the shaft.

Conclusion

Magnetic position sensors provide designers of industrial and automotive BLDC motor control systems with a small, robust, and easily assembled position sensing solution. The new ADA4571 from ADI improves on previous generations of magnetic position sensors by offering a high speed, high precision, production guaranteed total angular accuracy, integrated diagnostic functions, and low power operation modes.

ADI has taken particular care to ensure that the mounting and calibration setup of the part is simple, and that the software overhead on the user is reduced.

As a result, BLDC motor manufacturers can benefit from very accurate position data, and consequently, high levels of torque performance, even in high speed applications, while gaining all the benefits of using contactless magnetic sensing technology.

References

ADA4571 Data Sheet.

AA700 Application Note. AMR Free Pitch Sensoren für winkel– und Längenmessung. Sensitec.

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