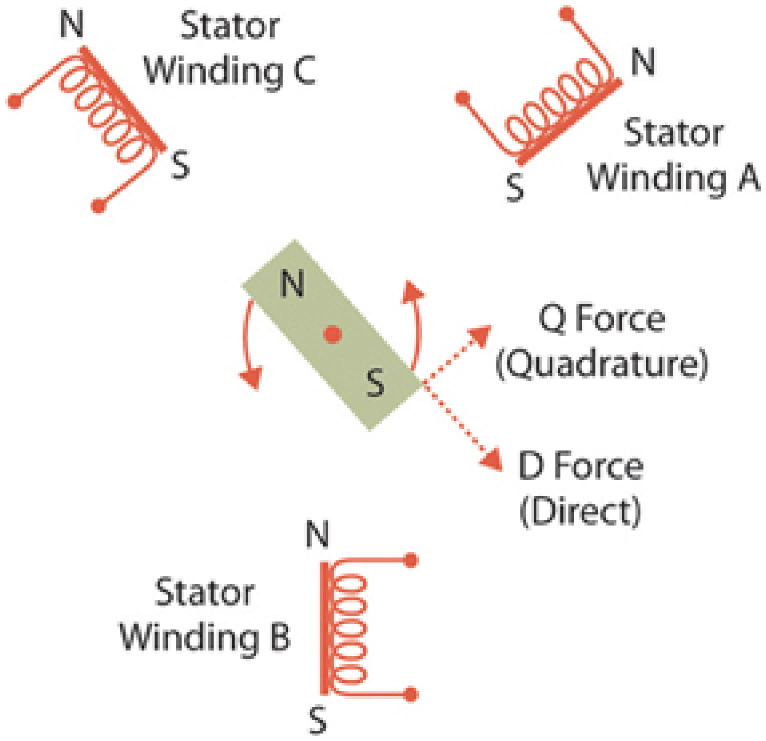
Brushless DC motor control techniques

Motor designs tend to evolve slowly, and engineers are generally cautious when it comes to changing time-honored approaches. Lately though, there has been a plethora of activity around the use of advanced control techniques for Brushless DC motors (also called synchronous AC motors). These techniques go well beyond the time honored 6-step trapezoidal drive and include sinusoidal drive and the more advanced techniques such as field oriented control. Finally, there is also an increasing interest in driving Brushless DC motors using a sensorless technique, even for applications that operate at zero speed.

This article will examine these trends with an eye toward determining what Brushless DC motor control techniques work best for a given application.

I see the body magnetic
For Brushless DC motors, magnetic fields are generated by magnets mounted directly on the rotor, and by coils in the stator. The stator windings generally come in a 3-phase configuration, and are arranged to be 120 electrical deg apart from each other. It is the sum of the force generated by these three phases that will ultimately generate useable motor rotation.

Depending on how the individual magnetic coils are phased, they can interact to create force that does not generate rotational torque, or they can create force which does drive rotation. These two different kinds of force are known as quadrature (Q) and direct (D), with the useful quadrature forces (not to be confused with quadrature encoding scheme for position feedback devices) running perpendicular to the pole axis of the rotor, and the non-torque generating direct forces running parallel to the rotor's pole axis. Figure 1 shows this.

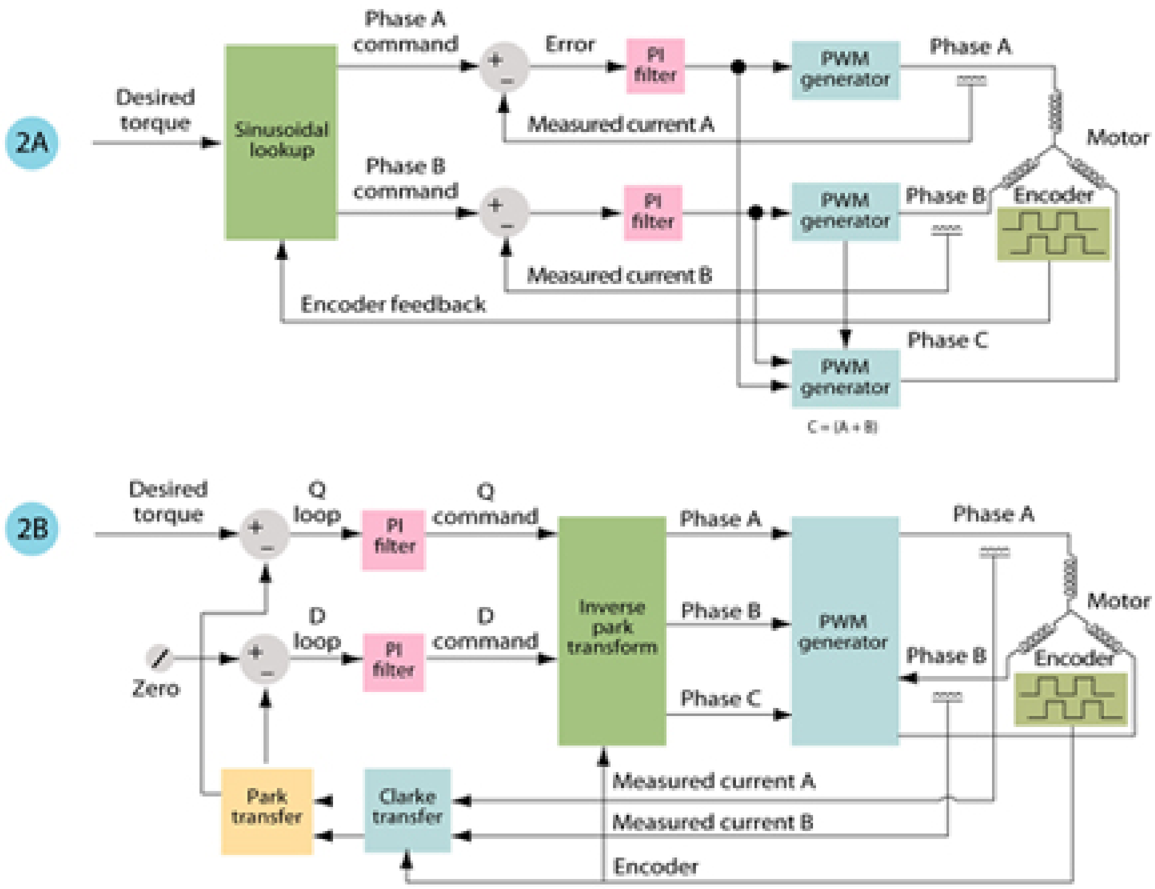


The trick to generating rotation is to maximize Q (quadrature) while minimizing D (direct) torque generation. If the rotor angle is measured using a Hall sensor or position encoder, the direction of the magnetic field from the rotor is known. Six step commutation is a simple technique that reads these Hall sensors and excites the coils in a specific sequence.

The downside to this technique is that for many motors it gives up some efficiency, and is not as smooth as more advanced techniques. Field oriented control is a much more sophisticated technique that addresses these problems.

What's your field oriented control?
Field oriented control (FOC) is an important control approach for Brushless DC motors. It resembles another, simpler, technique called sinusoidal commutation, but as the snarky adage goes - it is similar but different.

Figure 2 shows control schemes for both sinusoidal commutation and field oriented control. In the sinusoidal control approach, the torque command is 'vectorized' through a sinusoidal lookup table, thereby developing a separate command for each winding of the motor. As the rotor advances, the lookup angle advances in kind. Once the vectorized phase command is generated, it is passed on to a current loop, one for each winding, which attempts to keeps the actual winding current at the desired current value.



An important feature of this approach is that as the frequency of motor rotation increases, so does the challenge of maintaining the desired current. This is because the current loop is affected by the rotation frequency. Lag in the current loop, insignificant at low rotation speeds, generates increasing amounts of D (unwanted) torque at higher rotation speeds, resulting in a reduction of available torque.

The control scheme for a field oriented control (FOC) approach differs in that the current loop occurs de-referenced from the motor's rotation. That is, independent of the motor's rotation. In the FOC approach there are two actual current loops, one for the Q torque, and one for the D torque. The Q torque loop is driven with the user's desired torque from the servo controller. The D loop is driven with an input command of zero, so as to minimize the unwanted direct torque component.

The trick to making all of this work are math-intensive transform operations that convert the vectorized phase angle to and from the de-referenced D and Q reference frame. While these transforms have been known about for years, their practical implementation in Brushless DC and AC Induction drives is now relatively commonplace due to the availability of low cost, high performance DSPs and microprocessors.

In addition to a higher top speed, brushless motors which adopt an FOC approach can be driven more efficiently, achieving efficiencies of up to 95 %. Sinusoidal commutation for Brushless DC motors also works very efficiently, but is not as efficiently as FOC at the higher speed ranges of the motor.

A motor without sensors is like a...

In recent years, there has been increasing interest in driving brushless DC motors without any position or commutation sensors. The traditional view of sensorless motor schemes is that it is a cost saving measure for high volume applications such as disk drives.

While it is true that eliminating the sensors lowers cost, for many applications, the real advantage is that it can eliminate the delicate electronics that go along with position sensors. Many industry applications such as transportation vehicles, HVAC (heating, ventilating and air conditioning), industrial pumps, and drilling, operate in very harsh environments, and attain significantly improved MTBF (mean time between failure) when electronics at the motor can be eliminated.

There are three overall sensorless drive techniques in use today. These are back EMF (electro motive force) measurement, flux linkage, and induction measurement. The first two techniques are used when the motor is rotating, and allow the rotor position to be estimated with increasing accuracy as the speed increases.

Toward the zero speed range, the induction measurement technique is used. A few different methods have been developed to accomplish this, but they all rely on the fact that even when not moving, the rotor position of a brushless DC motor has a slight effect on the electrical characteristics of the coils. This small affect can be measured, particularly for motors that have larger saliency, and the rotor position can be inferred from this measurement.

Unfortunately, many application and motor combinations can not be practically driven to zero speed using a sensorless technique, so for the most part, sensorless drive techniques move through the zero speed regime so that they can operate reliably at speed by measuring back EMF waveforms.

From a practical standpoint, this means that positioning applications generally still require a full complement of sensors. But for applications with reasonably predictable loads, sensorless drives can increasingly be used to effectively control velocity and torque even at fairly load speeds.

Summary

Developments in control techniques, a growing demand for energy efficiency, and widely available low cost DSPs and microprocessors, have combined to significantly raise the bar for Brushless DC motor performance.

Leading the charge for greater efficiency and robustness are the twin techniques of field oriented control and sensorless drive. Many applications can use these techniques in combination, creating a powerful approach for a high performance, low cost, and very robust motor drive.

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