Special Report

Motors & Motion Control Subsystems

Edited by Jean Miller, Managing Editor

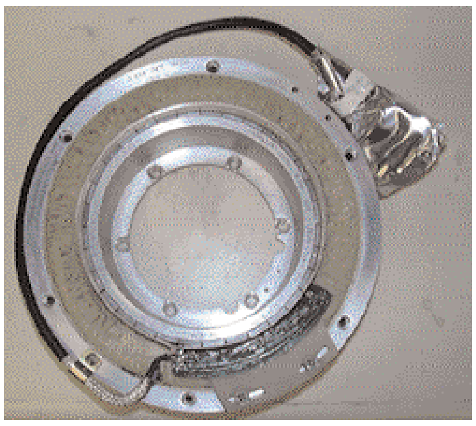
The Proper Kind of DC Brushless Motor Controller

by Dan Williams, M.S. Kennedy Corp.

When making a DC brushless motor controller choice, there are several issues that have to be addressed so that the proper device is selected for a system. If the application is a simple fan or blower, a rather simple speed controller with just an over-current limit is all that may be necessary. If the direction of the motor needs to be changed, this has to be taken into account in the controller selection. If torque needs to be controlled, a controller with a current loop control needs to be specified. If the application calls for a high bandwidth servo control loop, a full four-quadrant controller must be chosen.

Quadrants of Operation

There are four possible modes or quadrants of operation using a DC motor, brushless or otherwise. In an X-Y plot of speed versus torque, Quadrant I is forward speed and forward torque. The torque is propelling the motor in the forward direction. Conversely, Quadrant III is reverse speed and reverse torque. Now the motor is "motoring" in the reverse direction, spinning backwards with the reverse torque. Quadrant II is where the motor is spinning in the forward direction, but torque is being applied in reverse. Torque is being used to "brake" the motor, and the motor is now generating power as a result. Finally, Quadrant IV is exactly the opposite. The motor is spinning in the reverse direction, but the torque is being applied in the forward direction. Again, torque is being applied to attempt to slow the motor and change its direction to forward again. Once again, power is being generated by the motor.



The pancake motor used for driving the gimbal.

A one-quadrant motor controller will drive the motor in one direction only. An example of this would be a small fan or blower, such as the brushless fans used on some PC power supplies. A small pump that only needs to run in one direction can also use such a controller. A two-quadrant controller has the capability of reversing the direction of the motor. If the pump needs to be backed up, this would be the controller to use. A four-quadrant controller can control the motor torque both in the forward and the reverse direction regardless of the direction of the motor. A servo control system needs just this kind of control.

In order to have complete control of torque, the feedback loop has to allow the amplifier to maintain control of the torque at all times. A missile fin actuator or antenna pointing system needs to have complete control of motor torque at all times in order to satisfy the system requirements. Examining what happens during the PWM sequence will reveal the difference in controllers.

PWM Proportional Control

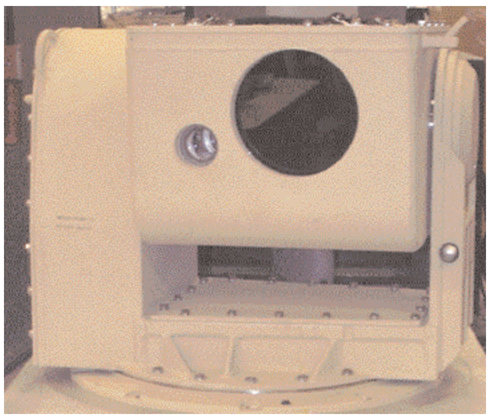
Pulse width modulation, or PWM is the method by which all class D amplifiers operate. By turning the supply voltage on and off at a high rate to a load and letting the characteristics of the load smooth out the current spikes, a much more efficient means of varying the power to the load will be achieved. Put a switch between one end of a DC brushed motor and the supply and another switch between the other end of the motor and the return to the supply. Modulating the on-off duty cycle of one or both of the switches will result in the proportional control of power to the motor, in one direction only. This is how one-quadrant operation is achieved.

Adding a second pair of switches to the first pair, basically making two totem pole half bridges, is how a two-quadrant controller is constructed. Modulating one or both of the second pair of switches will result in controlling the motor in the opposite direction. This is operation in quadrant three.

The construction of a four-quadrant controller is exactly the same as the two-quadrant controller. The difference is in the modulation of the four switches. By modulating the opposite pairs of switches together in a complementary fashion, there is modulation control occurring at all times. In the two-quadrant case, as the motor either stops or changes direction, the modulation decreases to zero and starts back up the opposite way. The control loop is out of control during the time the modulation is stopped. With a four-quadrant controller, modulation is occurring at a 50 percent duty cycle when the motor is not turning. The controller maintains control as the motor speed passes through zero. The net result is tighter control without any discontinuity at zero, and the bandwidth capability of the control system is doubled because, in effect, double the supply voltage is being utilized at all times.

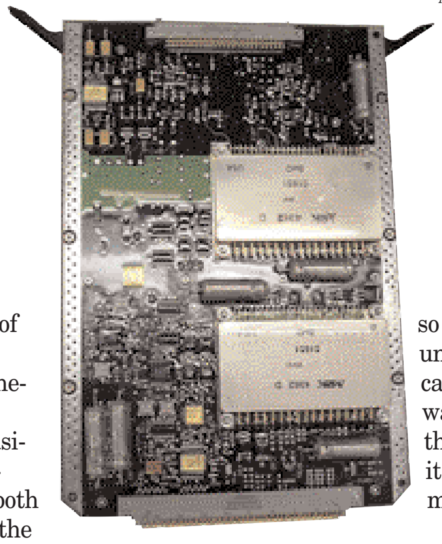
Using this concept in a three-phase brushless DC motor controller, another half bridge is added. The pairs of half bridges are controlled by the Hall sensors, as they electrically commutate the motor with the three half bridges. At any given time, only two of the half bridges are being used, but they are modulated exactly as discussed previously. This method of control is the basis for the MSK4362 three-phase brushless DC motor controller.

The MSK4362 is a full four-quadrant DC brushless motor control "torque amplifier." It is designed to provide closed loop current control of a brushless motor by sensing the current through the motor, thereby controlling the torque output of the motor. In a DC motor, torque is proportional to current. Enough torque produces speed, and the MSK 4362 is used as the inner loop of a servo speed control system. By controlling torque directly instead of speed, better control of a motor in a servo system is realized. In other controllers, the loop control is lost as the controller passes through zero torque. This is not acceptable in most servo control systems. This discontinuity will disrupt the control system in many cases.



CIV (Commander's Independent Viewer) infrared gimbal for the Bradley Fighting Vehicle from United Defense L.P.

Several years ago, Raytheon Systems was experimenting with a controller for running the stabilization system for the Commander's Independent Viewer (CIV), an infrared observing aid for the Bradley Fighting Vehicle, developed and manufactured for the U.S. Army by United Defense L.P. In image stabilization, most of the controlling is done right around a given point in space. This means that the system is constantly moving to continue pointing at a target but has to be able to respond quickly to changes in commanded torque as the vehicle is bouncing up and down. There are large torque disturbances, but not necessarily a lot of motor movement. The controller in question did not have the capability of controlling successfully around zero and with fast controlled torque reversal, so it was found to be unsuitable for the application. The MSK 4362 was then used in place of the other controller, and it satisfied the requirements of the system.



Close-up view of the two axis motor controller card.

The gimbals can be operated in either position mode or stabilization mode. In position mode, the gimbal control loop holds the gimbal in a given position with respect to the vehicle. An angle-measuring resolver is used as the loop feedback element in position mode. In stabilization mode, the gimbal control loop holds the gimbal in a given orientation in space. This allows the CIV optical viewing system to remain fixed on a distant target while the vehicle is "on the move." An inertial angular-rate measuring gyroscope is used as the loop feedback element in stabilization mode. In either mode, the gimbal controller sends a torque command signal to the motor current loop closed by the MSK4362 motor controller.

In the CIV system, high slew rate is not of primary concern, but high torque is. The maximum required slew rate for the gimbal was 60 degrees per second, and the minimum was 0.00278 degrees per second. In most stabilized gimbal systems, maximum slew rates are small compared to other types of servo systems. Peak currents during testing were found to be in excess of 25 A. To be able to obtain the greatest amount of torque possible, pancake motors were used instead of canned servo motors. Brushless DC pancake torque motors with integrated Hall Effect sensors were chosen to drive the two CIV system gimbals. The Hall sensor outputs are fed to the MSK4362 controller to commutate the internal three-phase bridge.

In the process of selecting a brushless DC motor controller, understanding the electrical requirements of the controller plus understanding the physical and performance requirements placed on the motor are paramount to achieving a successful system design. Studying the quadrants in which the motor has to operate will help tremendously in picking out the correct PWM modulation for the controller. Finally, selecting the input requirements to the controller so that the correct control loops can be established will ensure success in implementing the correct controller in a system.

I would like to thank Jim Clemenger, James Debruin and Dan Sparks of Raytheon Systems for their input and support during the writing of this article.

Dan Williams is a Design Engineer at M.S. Kennedy Corp., and is responsible for their motor control product design and development. He can be reached at 4707 Dey Rd., Liverpool, N.Y. 13088; (315) 701-6751 ext. 211; d.williams@mskennedy.com; www.mskennedy.com.

EDITORIAL EVALUATION

Write in Number or Reply Online

I found this article:

Very Useful	Useful	Not Useful
xxx	xxx	xxx