Matching servomotors and amplifiers

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Properly matching brush-type and brushless dc (BLDC) motors and amplifiers is essential to obtaining a high-performance motion system. This article gives you tips on how to do it.

Successfully implementing a brushless (BLDC) servo motion control system requires — at the very least — understanding the operating parameters of each element in the system: motor, amplifier, feedback devices, motion controller, and all power transmission devices, Figure 1. One of the most complex relationships centers on properly matching servo motor and amplifier. These two elements share significant and subtle interactions that are key to achieving optimum system performance.

To better understand the matching process requires knowing how each operates and some of the basic operational equations.

Motor equivalent circuit

For a brush-type dc motor, the amplifier bus must deliver enough voltage and current to satisfy Equation 1, which is derived from the brush dc servo motor's electrical characteristics as shown in Figure 2.

$$V_B \geq R_{M(\text{Hot})}I_M + L_M dI_M / dt + K_E N \quad (1)$$

This equation also applies to nonsinusoidal commutation of BLDC motors.

Nomenclature

I_M = Motor current (equivalent to T_L/K_t), A

I_p = Peak current, A

K_E = Back EMF/krpm

K_t = Torque constant

L_m = Motor inductance, h

N = Speed, krpm

R_a = Armature resistance, Ω

R_M = Hot motor resistance, Ω

T = Torque

T_p = Peak torque

V_{brush} = Brush drop (approx. 1-2 volts)

V_B = Bus voltage, V

V_m = Applied motor voltage, V
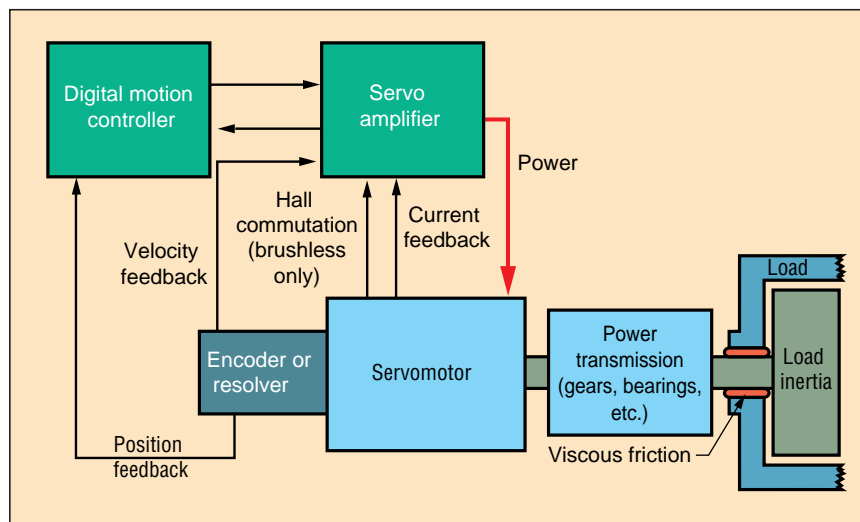
V_{sat} = Amplifier saturation voltage, V

This is *not* the case with sinusoidal commutation, because all three windings are excited simultaneously. The resultant voltages and torque values are intertwined with the amplifier switching frequency, characteristics of the output power stage, feedback device that pro-

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Figure 1 — Basic servo system with typical feedback circuits.

Figure 2 — Brush-type dc and brushless dc (BLDC) servo amplifier output stage and servo motor equivalent circuit.

vides the commutation, and the motor design. Thus, it is important that the sinusoidal amplifier and BLDC motor be tested as a system to avoid any performance surprises.

Amplifier switching frequency

In general, a high-switching frequency (20 kHz and more) by PWM amplifiers enables using motors with low inductance, high-energy magnets, and less wire. Such motors can operate at high speeds, with relatively low voltage (including 24-Vdc), and yet offer fast response.

The minimum rated inductance is voltage dependent. If it is rated at 2 mH at 100V, it will be 6 mH at 300 V, because of the power loss in the amplifier that is a function of the slew rate.

Torque ripple

A nonsinusoidal drive applied to a sinusoidal motor may produce torque ripple (equation 2) approaching 15%. Moreover, if 180-deg square-wave phase currents are applied to a mismatched motor, it can develop 40% torque ripple.

$$T_r = \frac{T_{\max} - T_{\min}}{T_{\max}} \qquad (2)$$

By contrast, torque ripple of a sinusoidal drive theoretically can approach zero. In practice, torque is a function of load inertia, motor design parameters — such as stator-tooth-tip design, winding

pattern distribution, rotor slewing, etc. — and current harmonics, because no waveform is a pure sine wave. Therefore, the torque ripple may exceed zero, but it will be much closer to zero than other alternatives.
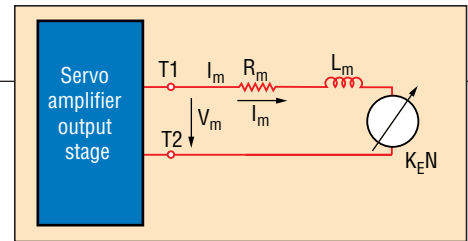
Amplifier current limiting

Servo amplifiers contain two types of current limit. One protects against sustained (continuous) overcurrents to protect the motor from exceeding its maximum continuous torque rating. It also prevents the amplifier from self destruction.

Set higher than the continuous value, the second type of current limit protects against excessive short-term (peak) currents. It enables the motor to deliver a high-output torque for short durations. Plus, it provides protection from motor demagnetization.

For brush-type motors, peak current limiting helps protect the brushes and commutator from arcing and exceeding current density limits.

Regardless of the type of motor and drive, it is vital to ensure that the amplifier can supply sufficient current to generate the continuous and peak torques required by the application.

As an example of what can occur when system components are mismatched, Figure 3 shows an amplifier that will allow the motor to achieve its continuous torque rating. However, the peak torque of the motor will never be reached be-

cause the amplifier's current-limit control limits the motor's output torque to 101 lb-in. while the motor's peak torque rating is actually 150 lb-in. In applications that require peak torque to accelerate the load, this limitation may be a severe penalty to pay for rather conservative protection against excessive peak-torque overloads.

A worst-case scenario is indicated in Figure 4. In this example, the continuous current rating of the amplifier is so low that it restricts the continuous output torque of the motor to 42% of its capability. Moreover, the peak torque capability of the motor is limited to 27% of its capacity.

Commutation limits

Brush-type motors are limited by the watts that can be switched (commutated). Each such motor has a commutation curve that indicates the speed and load that sparking between the brushes and commutator bars begins, Figure 5. It is important to operate below this threshold to ensure rated motor life.

Motor winding construction

If an SCR amplifier is used, the motor windings may need to be braced due to the high surge currents inherent in an SCR-
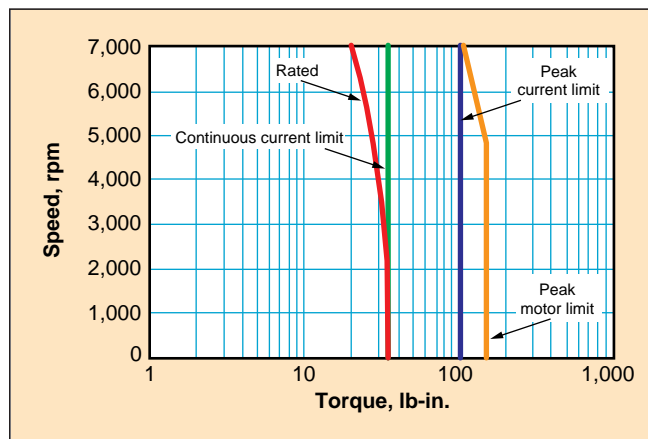
Figure 3 — Typical BLDC motor operating curves with drive protective (overcurrent) values.
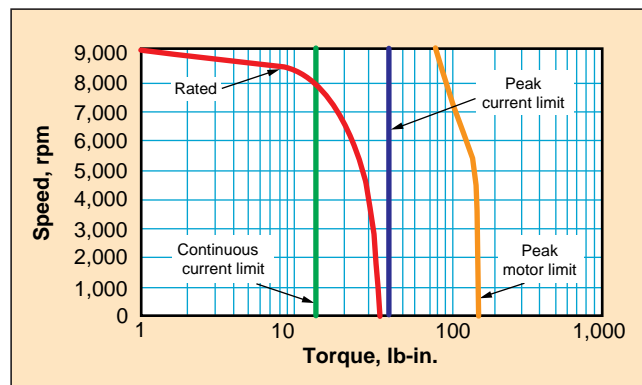
Figure 4 — BLDC motor operating curves with conservative drive protective (overcurrent) values. These settings are so low in relation to the motor capabilities that they may prevent the motor from delivering sufficient accelerating torque.

based drive. Adding inductors to reduce the rate of rise of this surge current is another possibility, but again this approach adds cost and lowers system efficiency.

Power supply and amplifier voltage

The amplifier must have sufficient bus voltage for the selected motor's anticipated peak speed and torque (Equation 1). All voltage drops must be considered including those in the motor and the connecting cables.

To determine the power supply and amplifier voltage needed for the application of a brush system, the following general equation can be used.

A properly matched system must also consider energy storage capacity of the bus filter capacitors. These capacitors

$$V_m = N \times K_E + \left(\frac{T_p}{I_p} \times 1.5 R_a \right) \quad (3)$$

$$+ V_{brush} + V_{sat}$$

minimize the supply voltage ripple and ensure that an adequate bus voltage is available upon demand. The capacitors are also instrumental in absorbing excess regenerated motor energy during changing load conditions, such as deceleration. For certain applications, the size of the bus capacitors and the addition of a shunt regulator must be carefully considered.

Form factor

Motor form factor is defined as the ratio of rms motor current to average motor current, expressed as:

$$FF = \frac{I_{rms}}{I_{avg}} \quad (4)$$

Excess ripple current in the motor can cause the motor to overheat, exhibit poor low-speed performance, reduce system response, and increase audible noise. Depending on the amplifier being used, the motor may have to be derated substantially. For example, a derating of 30% to 60% is typical when using a full-wave, single-phase, SCR type controller that typi-
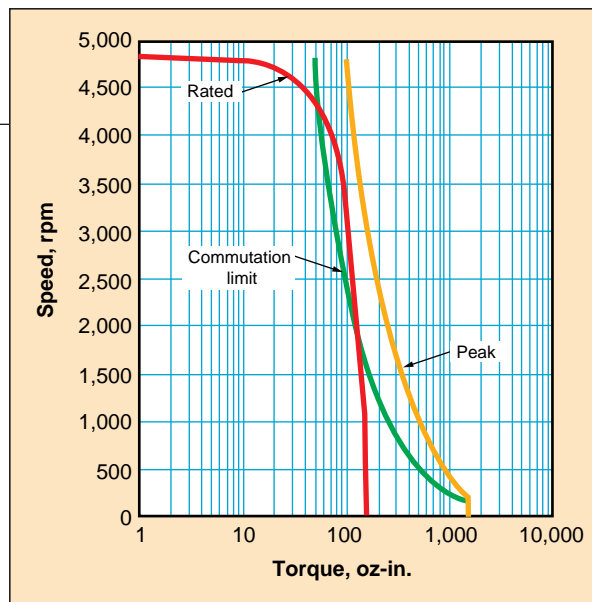

Figure 5 — Typical brush-type dc motor with rated, communication limits, and reak overcurrent values.
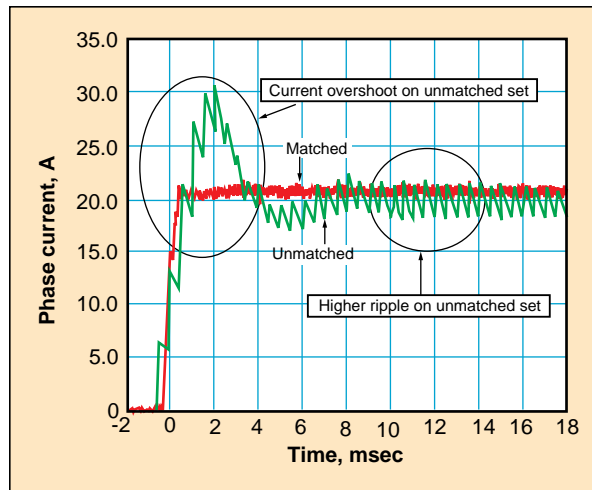

Figure 6 — Comparison of matched and unmatched servo current loops. These current values indicate output torque.

cally has a form factor of 1.1 to 1.85 . However, PWM controllers, can provide a form factor that approaches unity.

Impedance matching

The amplifier must be tuned to optimize performance by adjusting its control loops. This involves setting parameters such as the velocity and current loop gains, notch filtering, current limiting, etc.

Figure 6 compares the servo current response vs. time for a matched and unmatched servo motor and amplifier. The initial response of a current loop change is analogous to an acceleration motion profile. The matched motor-amplifier current response has a faster rise time, less overshoot, and lower current ripple. The amplifier engineer can tune the motor current loop to maxi-

mize system power over a wide frequency range by adjusting the inductance compensation, which is usually called "current loop gain."

Ambient temperature

Many manufacturers rate motors and amplifiers at different ambient temperatures. Derate one or more of the individual components, if the ambient temperature will be higher than the specified operating ambient for that component.

Terminations and feedback devices

To ease the installation phase, assure the terminations between the amplifier and motor are compatible. Some motors are supplied with cables and plugs, and many amplifiers are fitted with screw terminals.

For feedback devices, two aspects must be covered: terminations and available power for encoders and other similar devices. Assure there is a match for both voltage and capacity. ■

*To obtain information on the CMC Motionmaster software package for modeling and sizing motion system components, please **circle 301** on the reader service card.*