The basics of motion control—Part 2

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In this concluding article, we show you how to use information on drive mechanics to easily determine the right motor and control for any electromechanical positioning application.

Once the mechanics of the application have been analyzed, and the friction and inertia of the load are known (see Part 1, *PTD*, 9/95, p43), the next step is to determine the torque levels required. Then, a motor can be sized to deliver the required torque and the control sized to power the motor. If friction and inertia are not properly determined, the motion system will either take too long to position the load, it will burn out, or it will be unnecessarily costly.

Motion control

In a basic motion-control system, Figure 1, the load represents the mechanics being positioned. The load is coupled or connected through one of the mechanical linkages described in Part 1.

The motor may be a traditional PMDC servo motor, a vector motor, or a brushless servo motor. Motor starting, stopping and speed are dictated by the control unit, which takes a low-level incoming command signal and amplifies it to a higher-power level for controlling the motor.

The programmable motion controller is the brain of the motion system and controls the motor control (amplifier). The motion controller is programmed to accomplish a specific task for a given application. This controller reads a feedback

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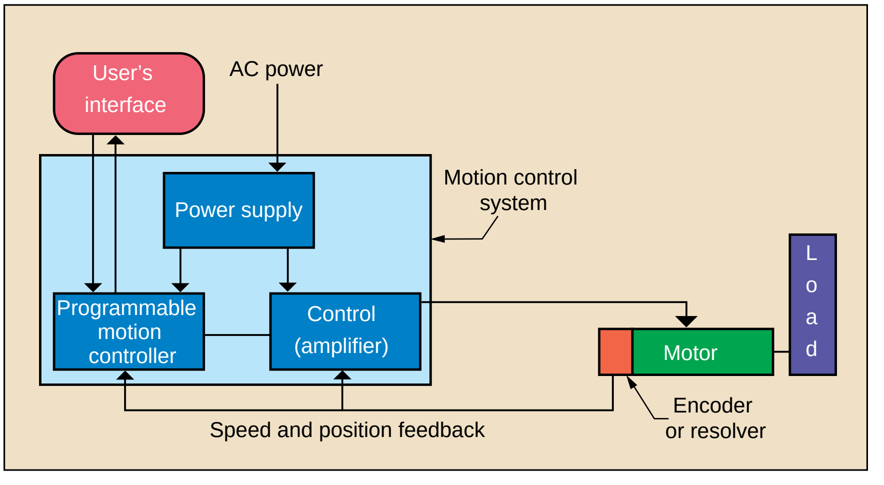

Figure 1 — Basic motion system.

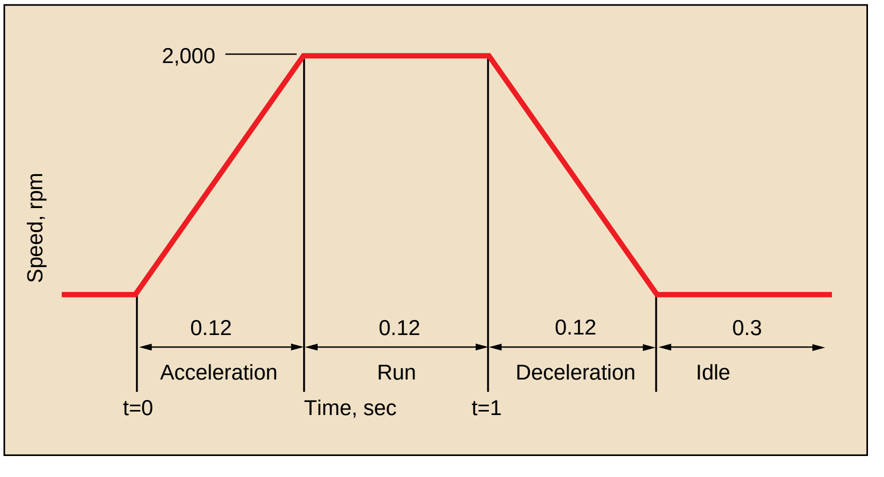

Figure 2 — Move profile.

Nomenclature:

α_{acc} = Rotary acceleration, rad/sec^2
I_{acc} = Current during acceleration, A
I_{rms} = Root-mean-squared current, A
J_{ls} = Leadscrew inertia, lb-in.-sec^2
J_m = Motor inertia, lb-in.-sec^2
J_t = Total inertia (load plus motor), lb-in.-sec^2
K_t = Torque constant, lb-in./A
P = Total power, W
P_{del} = Power delivered to the load, W
P_{diss} = Power (heat) dissipated by the motor, W
R_m = Motor resistance, Ω
S_m = Motor speed, rpm
t_{acc} = Acceleration time, sec
t_{dec} = Deceleration time, sec
t_{idle} = Idle time, sec
t_{run} = Run time, sec
T = Torque, lb-in.
T_{acc} = Acceleration torque, lb-in.
T_{dec} = Deceleration torque, lb-in.
T_f = Friction torque, lb-in.
T_{rms} = Root-mean-squared torque, lb-in.
T_{run} = Running torque, lb-in.
T_s = Stall torque, lb-in.

signal to monitor the position of the load. By comparing a pre-programmed, "desired" position with the feedback position, the controller can take action to minimize an error between the actual and desired load positions.

Movement profile

A movement profile defines the desired acceleration rate, run time, speed, and deceleration rate of the load. For example, suppose with a system at rest (time=0, Figure 2), the motion controller issues a command to the motor (through the servo control) to start motion. At t=0, with full power-supply voltage and current applied, the motor has not yet started to move. At this instant, there is no feedback signal, but the error signal is large.

As friction and torque are overcome, the motor and load begin to accelerate. As the motor approaches the commanded speed, the error signal is reduced and, in turn, voltage applied to the motor is reduced. As the system stabilizes at running speed, only nominal power (voltage and current) are required to overcome friction and windage. At t=1, the load approaches the desired position and begins to decelerate.

In applications with similar move profiles, most of the input energy is dissipated as heat. Therefore, in such systems, the motor's power dissipation capacity is the limiting factor. Thus, basic motor dynamics and power requirements must be determined to ensure adequate power capability for each motor.

Determining acceleration rate is the first step. For example, with a movement profile as shown in Figure 2, the acceleration rate can be determined from the speed and acceleration time. (Dividing the motor speed expressed in rpm by 9.55 converts the speed to radians per second.)

$$\alpha_{acc} = \frac{S_m}{9.55 t_{acc}} \qquad (1)$$

$$\alpha_{acc} = \frac{2{,}000}{9.55(0.12)} = 1{,}745.2 \text{ rad/sec}^2$$

Acceleration torque

The torque required to accelerate the load and overcome mechanical friction is:

$$T_{acc} = J_t(\alpha_{acc}) + T_f \qquad (2)$$

$$= (J_t + J_{ls} + J_m)\alpha_{acc} + T_f \qquad (3)$$

Example: Our application, Figure 3, requires moving a load through a leadscrew. The load parameters are:

Weight of load (W_{lb}) = 200 lb

Leadscrew inertia (J_{ls}) = 0.00313 lb-in.-sec^2

Friction torque (T_f) = 0.95 lb-in.

Acceleration rate (α_{acc}) =1745.2 rad per sec^2

Typical motor parameters:

Motor rotor inertia (J_m) = 0.0037 lb-in.^{2}

Continuous stall torque (T_s) = 14.4 lb-in.

Torque constant (K_t) = 4.8 lb-in./A

Motor resistance (R_m) = 4.5 Ω

Acceleration torque can be determined by substituting in equation 3

$$T_{acc} = (.00052 + .00313 + .0037)1745.2 + .95$$
$$= 13.75 \text{ lb-in.}$$

Duty cycle torque

In addition to acceleration torque, the motor must be able to provide sufficient torque over the entire duty cycle or movement profile. This includes a certain amount of constant torque during the run phase, and a deceleration torque during the stopping phase.

Running torque is equal to friction torque (T_f), in this case, 0.95 lb-in.

During the stopping phase, deceleration torque is:

$$T_{dec} = -J_t(\alpha_{acc}) + T_f \qquad (4)$$
$$= -(.00052 + .00313 + .0037)1{,}745.2 + .95$$
$$= -11.85 \text{ lb-in.}$$

Now, the root-mean-squared (rms) value of torque required over the movement profile can be calculated:

$$T_{rms} = \sqrt{\frac{T_{acc}^2(t_{acc}) + T_{run}^2(t_{run}) + T_{dec}^2(t_{dec})}{t_{acc} + t_{run} + t_{dec} + t_{idle}}} \qquad (5)$$

$$= \sqrt{\frac{(13.75)^2(.12) + (.95)^2(.12) + (11.85)^2(.12)}{.12 + .12 + .12 + .3}}$$

$$= 7.73 \text{ lb-in.}$$

The motor tentatively selected for this application can supply a continuous stall torque of 14.4 lb-in., which is adequate for the application.

Control requirements

Determining a suitable control (amplifier) is the next step. The control must be able to supply sufficient accelerating current (I_{acc}), as well as continuous current (I_{rms}) for the application's duty-cycle requirements.

Required acceleration current that must be supplied to the motor is:

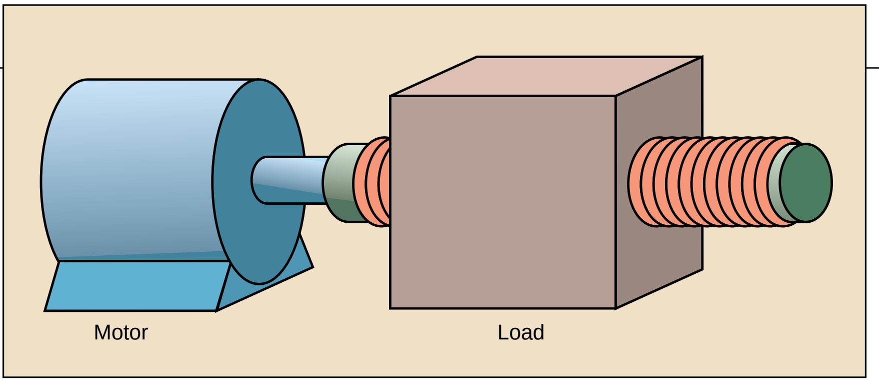

Figure 3 — Motor-leadscrew configuration.

$$I_{acc} = \frac{T_{acc}}{K_t} \quad (6)$$

$$= \frac{13.75}{4.8} = 2.86 \text{ A}$$

Current over the duty cycle, which the control must be able to supply to the motor, is:

$$I_{rms} = \frac{T_{rms}}{K_t} \quad (7)$$

$$= \frac{7.73}{4.8} = 1.61 \text{ A}$$

Power requirements

The control must supply sufficient power for both the acceleration portion of the movement profile, as well as for the duty-cycle requirements. The two aspects of power requirements include (1) power to move the load, P_{del}, and (2) power losses dissipated in the motor, P_{diss}.

Power delivered to move the load is:

$$P_{del} = \frac{T(S_m)(746)}{63{,}025} \quad (8)$$

Power dissipated in the motor is a function of the motor current. Thus, during acceleration, the value depends on the acceleration current (I_{acc}); and while running, it is a function on the rms current (I_{rms}). Therefore, the appropriate value is used in place of "*I*" in the following equation.

$$P_{diss} = I^2(R_m) \quad (9)$$

The sum of these P_{del} and P_{diss} determine total power requirements.

Example: Power required during the acceleration portion of the movement profile can be obtained by substituting in equations 8 and 9:

$$P_{del} = \frac{13.75(2{,}000)}{63{,}025}(746) = 325.5 \text{ W}$$

$$P_{diss} = (2.86)^2(4.5)(1.5) = 55.2 \text{ W}$$

$$P = P_{del} + P_{diss}$$

$$= 325.5 + 55.2 = 380.7 \text{ W}$$

Note: The factor of 1.5 in the P_{diss} calculation is a factor used to make the motor's winding resistance "hot." This is a worst-case analysis, assuming the winding is at 155 C .

Continuous power required for the duty cycle is:

$$P_{del} = \frac{7.73(2{,}000)}{63.025}(746) = 182.9 \text{ W}$$

$$P_{diss} = (1.61)^2(4.5)(1.5) = 17.5 \text{ W}$$

$$P = 182.9 + 17.5 = 200.4 \text{ W}$$

In summary

The control selected must be capable of delivering (as a minimum) an acceleration (or peak) current of 2.86 A, and a continuous (or rms) current of 1.61 A. The power requirement calls for peak power of 380.7 W and continuous power of 200.4 W.

To aid in selecting both motors and controls (amplifiers), many suppliers offer computer software programs to perform the iterative calculations necessary to obtain the optimum motor and control.