Sizing a Servo System

Lesson #2 - Servo Motors and Torque

Background

Lesson #1 covered Newton's Laws and rotary motion concepts. In this lesson, we will discuss servo amplifiers and brushless motors as well as move profiling and torque calculations give the background necessary for servo sizing.

Part I - Servo Amp and Motors

A servo amplifier and motor have several key properties:
Torque constant: This is a property of the motor, expressed in in-lbs/Amp. From this you can see that the torque output of the motor is directly proportional to the current provided by the amplifier. This constant will vary depending on the construction of the motor and the winding properties.
Speed constant: This is a property of the motor, expressed in KRPM/Volt. From this you can see that the speed output of the motor is directly proportional the voltage output provided by the amplifier (NOTE: This is the DC bus voltage, NOT the AC input voltage). This constant will vary depending on the construction of the motor and the winding properties.
Rated torque at rated speed: This is the property of a motor/drive system. A speed/torque curve is usually necessary to view this point. A servo motor and amplifier system produce a torque/speed curve that is almost constant, up to a certain point. This point is known as the 'rated torque at rated speed' point.
Continuous duty: This is the range of torque/speed points that a motor and drive may operate in, indefinitely.
Intermittent duty: This is the range of torque/speed points that a motor and drive may operate in for a given amount of time (usually these points vary depending on the manufacturer's definition of 'intermittent' duty.

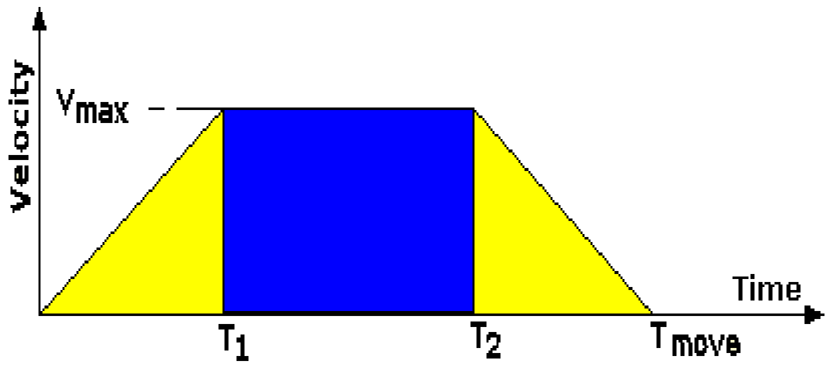
Part II - Sizing

For sizing a drive/motor combination for a periodic move profile, we need to know the following information (we could discuss non-periodic move profiles, but most real-world applications will be periodic):

1. 'Worse'-case move including the following variables:
    a. move time
    b. distance of move
2. Load inertia (this will include the load plus the motor, eventually)
3. Duty cycle
4. Any applicable information regarding friction

A. Move Profiling

For the ‘worse’ case move (i.e., fastest), we will construct a trapezoidal move profile. There are situations – although rare – where we would use a triangular move profile, but for now we will stick to the trapezoid.



Trapezoidal Move Profile

The total move time is represented by ‘T_{move}’; the time to accelerate is represented by ‘T_1’; the time when the deceleration begins is represented by ‘$T_1 + T_2$’. The total area under the two yellow triangles and the blue rectangle is the total distance moved. Lastly, the total cycle time is denoted by ‘T_{cycle}’.
Mathematically, since the total motion profile is a trapezoid, $T_1 = T_{move}/3 = T_2 – T_1 = T_{move} – T_2$.
We can now express one equation describing the move:
Move distance = $(1/2 * T_1 * V_{max}) + (T_1 * V_{max}) + (1/2 * T_1 * V_{max})$
Or, move distance = $(2 * T_1 * V_{max})$ where $T_1 = T_{move}/3$
Therefore the move distance = $(2/3 * T_{move} * V_{max})$.
Given the move distance and move time, we have one equation and one unknown, V_{max}.
Once we solve for V_{max}, we can then solve for the acceleration/deceleration which would be (V_{max}/T_1) or acceleration = $(3*V_{max})$. Once we calculate this velocity and acceleration/deceleration, we will be ready to move on to the calculation of the peak torque and RMS torque requirements for our drive/motor system.

B. Torque Calculations

I. Acceleration/Deceleration Torque

Given the load inertia and system coefficient of friction, we can calculate the peak and RMS torque requirements.
Remember Newton’s second law? F = ma? Well, we can extend this law to rotary motion in the following form:
Torque to accelerate = J * a, where ‘J’ is the load inertia and ‘a’ is the acceleration
It is important to be consistent with dimensions when applying these formulas. We will assume that ‘J’ is given in lb-in-s^2. If it is not, we can use an engineering reference book

or a table of conversions easily found in most motion catalogs to convert from other units.
Acceleration (found from Part A) will usually be expressed in RPM/second or R/s^2. We need to convert these units to $radians/s^2$. All we need to know for this is that there are 2 * Pi = 6.28 radians per revolution. Now just 'plug and chug'. The units for acceleration torque will be in in-lbs, as they should be!!
NOTE:
We also have to overcome any system friction to accelerate the load. We will denote this friction torque as 'T_f'. This friction torque is usually very minimal relative to the torque required to accelerate the load, so we will ignore it for now. When decelerating, this friction will aid stopping, not hinder it as it does when accelerating.

II. Constant Velocity Torque

The only torque requirement for moving at constant speed is that of overcoming friction, T_f. This is because the acceleration at constant speed is zero!! As with the acceleration/deceleration torque, we will ignore it.

III. RMS Torque

We will now calculate the RMS, or root-mean square torque (average torque) requirement for our system. The RMS torque can be calculated as follows:
$T_{rms} = [(2 * (T_{accel}^2 * t_{accel}))/t_{cycle}]^{1/2}$
Where t_{accel} = time to accelerate (T_1 from Part A) and t_{cycle} = cycle time (T_{cycle} from Part A); T_{accel} = Torque to accelerate (from Part B).
Once this has been done, you may want to use a 'safety' factor to increase the acceleration torque and RMS torque requirements (to be on the safe side). I usually use a safety factor of 10% (1.10). Then use the torque/speed curve from the motor/drive catalog to select the proper system. NOTE: You're not done, yet!!!
After you select a motor and drive, repeat Part B but add the inertia of the selected motor to the total inertia and make sure that the torque/speed curve is still valid for the application. If it is not, you must either select a larger motor/drive or reduce the acceleration torque requirements!!