# Engineering Notes

# Engineering Notes by Oriental Motor

## Motor Sizing Basics Part 3: Acceleration Torque (and RMS Torque)

Feb 27, 2020 9:05:40 PM / by Johann Tang



Now that we understand the calculations behind load torque and load inertia, we're two steps closer to motor selection. You might be wondering why I separated load torque and acceleration torque calculations. That's because in order to calculate for acceleration torque, load inertia and speed must be calculated first.

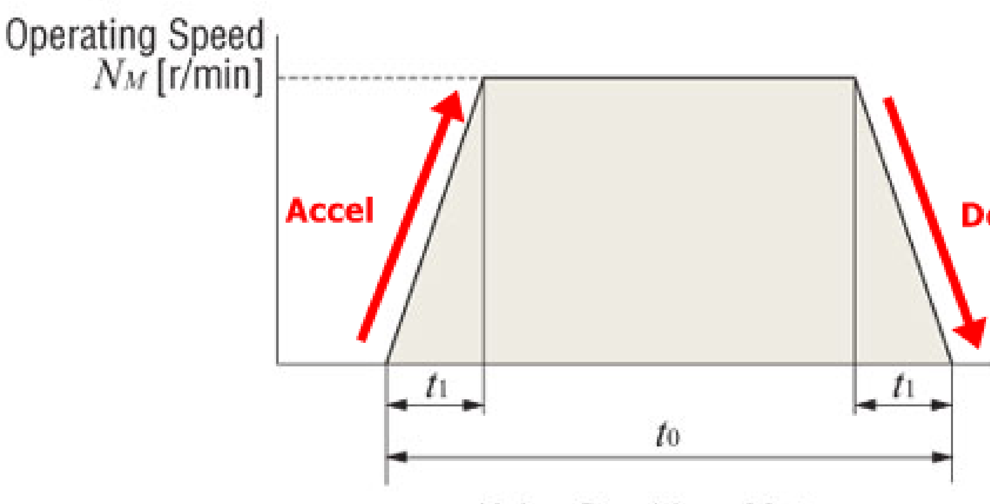
**Let's review first**

In **Motor Sizing Basics Part 1 - Load Torque**, **load torque** is defined as the amount of torque constantly required for application and includes friction load and gravitational load.

In **Motor Sizing Basics Part 2 - Load Inertia**, **load inertia** is defined as the resistance of any physical object to any change in its speed from the perspective of the rotational axis.

Here we show a typical motion profile with an acceleration, constant speed, and deceleration region.

- Start from zero speed
- Accelerate with t1
- Constant speed at Nm for a duration of t0-t1-t1
- Decelerate with t1
- Stop at zero speed




## Acceleration/Deceleration Torque

As opposed to load torque (which is constant), acceleration torque is the required torque to accelerate (or decelerate) an inertial load up to its target speed.  It is only present when accelerating (or decelerating) an inertial load.

## Total Required Torque

The total required torque is the sum of the load torque and acceleration torque as shown below (with a safety factor to cover for what we don't know).

$$T_M = (T_L + T_a) \times S_f$$

$T_M$ : Required torque
$T_L$ : Load torque
$T_a$ : Acceleration torque
$S_f$ : Safety factor

Mathematically, acceleration torque is made up of load inertia and acceleration rate as shown below. This is the most common equation used to calculate acceleration torque for all types of motors.

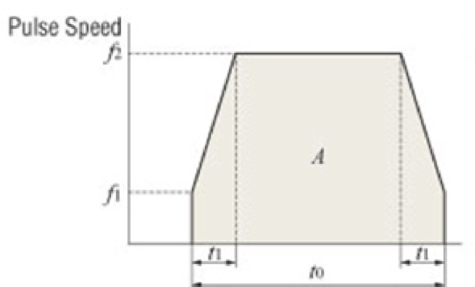
$$Ta = J \times A$$

$Ta$ : Acceleration Torque
$J$ : Moment of Inertia
$A$ : Acceleration Rate

Stepper motors and servo motors can use a different formula since they deal with pulse speed (Hz). There are two equations available for 2 types of motion profiles: with or without acceleration/deceleration.

① For acceleration/deceleration operation

$$T_a = (J_0 \cdot i^2 + J_L) \times \frac{\pi \cdot \theta s}{180} \times \frac{f_2 - f_1}{t_1}$$

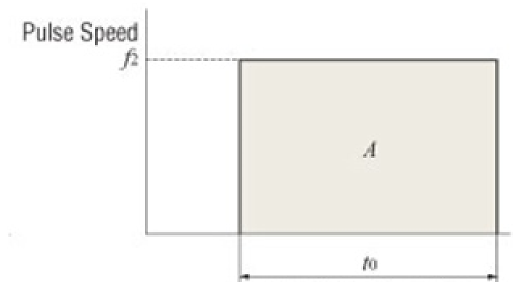


Acceleration/Deceleration Operation

② For start/stop operation

$$T_a = (J_0 \cdot i^2 + J_L) \times \frac{\pi \cdot \theta s}{180 \cdot n} \times f_2^2$$

n: $3.6° / (\theta s \times i)$



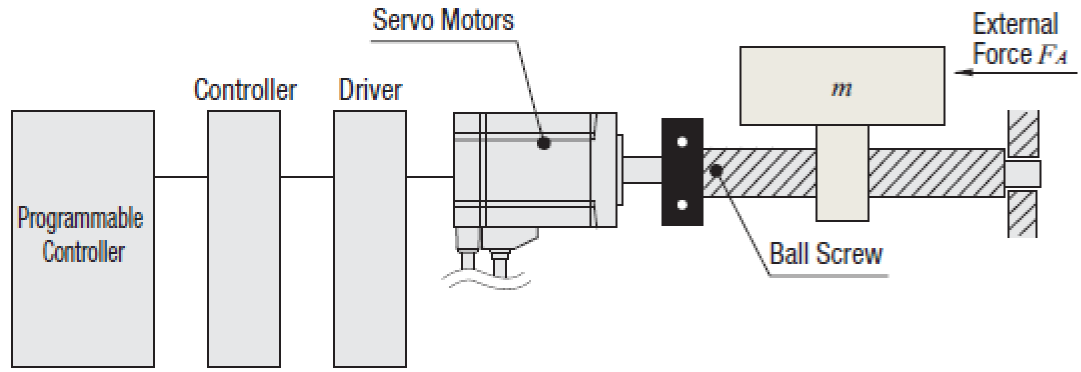
Start/Stop Operation

**Why use acceleration/deceleration at all?**

That's because even though immediately starting at the target speed might seem easier, but it results in a lot of acceleration torque, and thus requires a bigger motor. A bigger motor also equals higher cost and bigger footprint, which are not the most desirable for machine designs.

## Example: Calculation of Load Torque and Load Inertia

In the following example, let's try to calculate load torque, load inertia, and acceleration torque using what we've learned so far. For me personally, I calculate load inertia first, then load torque, then speed, then acceleration torque. Information below describes the motor mechanism and given parameters.




Max. table speed ........ $V_L = 0.2$ [m/s]
Resolution ........ $\Delta l = 0.02$ [mm]
Motor power supply ........ Single-Phase 115 VAC
Total mass of table and load ........ $m = 100$ [kg]
External ........ $F_A = 29.4$ [N]
Friction coefficient of sliding surface ........ $\mu = 0.04$
Ball screw efficiency ........ $\eta = 0.9$
Internal friction coefficient of preload nut ........ $\mu_0 = 0.3$
Shaft diameter of ball screw ........ $D_B = 25$ [mm]
Overall length of ball screw ........ $L_B = 1000$ [mm]
Ball screw lead ........ $P_B = 10$ [mm]
Ball screw material ........ Iron (Density $\rho = 7.9 \times 10^3$ [kg/m$^3$])
Operating cycle ....Operation for 2.1 seconds/stopped for 0.4 seconds (repeated)
Acceleration/deceleration time ........ $t_1 = t_3 = 0.1$ [s]

## Step 1: Load Inertia

Calculate the load inertia for the screw, then the table and load separately, then add them up. The load inertia can be used for a tentative motor selection, which I will explain in a bit.

Inertia of Ball Screw

$$J_B = \frac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B^4$$

$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 1000 \times 10^{-3} \times (25 \times 10^{-3})^4$$

$$\fallingdotseq 3.03 \times 10^{-4}\ [\mathrm{kg \cdot m^2}]$$

Inertia of Table and Load $J_m = m\left(\frac{P_B}{2\pi}\right)^2$

$$= 100 \times \left(\frac{10 \times 10^{-3}}{2\pi}\right)^2$$

$$\fallingdotseq 2.53 \times 10^{-4}\ [\mathrm{kg \cdot m^2}]$$

Inertia $J_L = J_B + J_m$

$$= 3.03 \times 10^{-4} + 2.53 \times 10^{-4} = 5.56 \times 10^{-4}\ [\mathrm{kg \cdot m^2}]$$

## Step 2: Load Torque

Use the load torque equation for screws and fill in all the blanks for the variables. Make sure to use the right equation for the specific application.

Operation direction load $F = F_A + m \cdot g\,(\sin\theta + \mu \cdot \cos\theta)$

$$= 29.4 + 100 \times 9.807\,(\sin 0^\circ + 0.04 \cos 0^\circ)$$

$$= 68.6\ [\mathrm{N}]$$

Load Torque of the Motor Shaft Conversion

$$T_L = \frac{F \cdot P_B}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}$$

$$= \frac{68.6 \times 10 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 22.9 \times 10 \times 10^{-3}}{2\pi}$$

$$\fallingdotseq 0.13\ [\mathrm{N \cdot m}]$$

Here $F_0 = \frac{1}{3} F$ represents the ball screw preload.

## Step 3: Speed (RPM)

The required speed is calculated with the following equation. Use the pitch/lead of the screw PB in order to convert linear speed to RPM.

$$N_M = \frac{60 \cdot V_L}{P_B} = \frac{60 \times 0.2}{10 \times 10^{-3}} = 1200\,[\text{r/min}]$$

FYI here's a common formula for all motors including acceleration.

**Common Formula for All Motors**

$$T_a = \frac{(J_0 \times i^2 + J_L)}{9.55} \times \frac{N_M}{t_1}$$

Here are some formulas for stepper motors when dealing in pulse speed (Hz).

### ●Formula for the Number of Operating Pulses $A$ [Pulse]

The number of operating pulses is expressed as the number of pulse signals that add up to the angle that the motor must rotate to get the load from point A to point B.

$$A = \frac{l}{l\mathrm{rev}} \cdot \frac{360°}{\theta s}$$

$l$ : Traveling Amount from point A to point B [m]
$l\mathrm{rev}$ : Traveling Amount per Motor Rotation [m/rev]
$\theta s$ : Step Angle [°]

### ●Formula for the Operating Pulse Speed $f_2$ [Hz]

The operating pulse speed can be obtained from the number of operating pulses, the positioning time and the acceleration (deceleration) time.

① For Acceleration/Deceleration Operation

The level of acceleration (deceleration) time is an important point in the selection. The acceleration (deceleration) time cannot be set easily, because it correlates with the acceleration torque and acceleration/deceleration rate.

Initially, as a reference, calculate the acceleration (deceleration) time at roughly 25% of the positioning time. (The calculation must be adjusted before the final decision can be made.)

$$t_1 = t_0 \times 0.25$$

$$f_2 = \frac{A - f_1 \cdot t_1}{t_0 - t_1}$$

② For Start/Stop Operation

$$f_2 = \frac{A}{t_0}$$

Use these formulas when appropriate. I usually use the first formula for AC motors, second formula for brushless motors, and third formula for stepper motors.

## Step 4: Acceleration Torque

Fill in the blanks for the variables. To determine J0, you first need to **tentatively select a motor** based on load inertia (as mentioned previously), then you can find the rotor inertia J0 for that motor.

### TIP: How To Tentatively Select a Motor Based on Load Inertia

For AC constant speed motors, AC speed control motors, and brushless speed control motors, you will need to look at the **permissible load inertia** values. For stepper motors or servo motors, you will need to know the allowable **inertia ratio** each type of motor can handle.

For stepper motors, the general guideline is to keep the inertia ratio (load inertia or reflected load inertia divided by rotor inertia) under 10:1, and 5:1 for faster motion profiles or smaller frame sizes than NEMA 17.

For closed-loop stepper motors, up to a 30:1 inertia ratio is recommended.

For auto-tuned servo motors, the inertia ratio increases to 50:1. For manual-tuned servo motors, it can increase to 100:1.

After you make a tentative motor selection based on load inertia, find the motor rotor inertia in the specifications, then plug the value for J0 in order to complete the acceleration torque calculation.

$$T_a\ (= T_d) = \frac{(J_L + J_0)\, N_M}{9.55\, t_1}$$

$$= \frac{(5.56 \times 10^{-4} + 0.162 \times 10^{-4}) \times 1200}{9.55 \times 0.1} \fallingdotseq 0.72\ [\mathrm{N{\cdot}m}]$$

## Step 5: Total Required Torque and Safety Factor

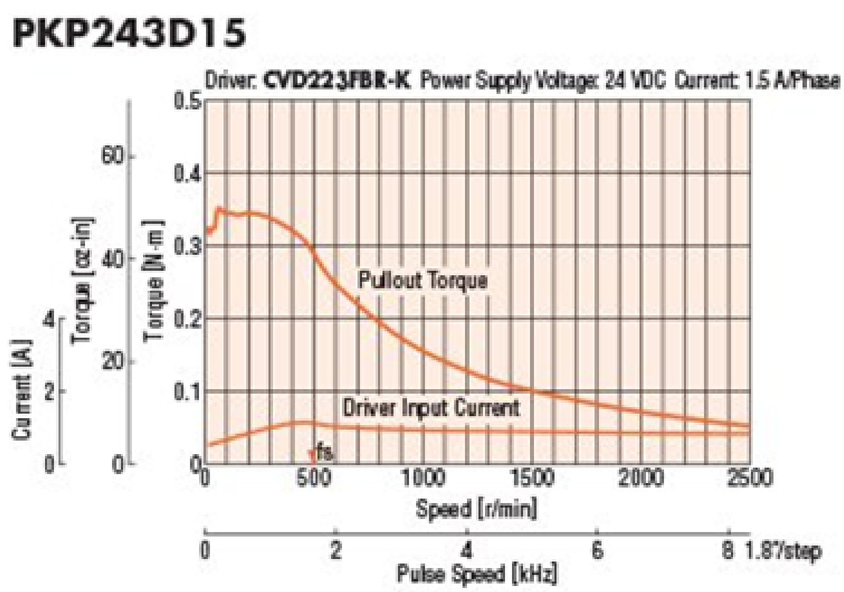
Add up the load torque and acceleration torque for total required torque. We will need a stepper motor that can output 0.85 Nm torque at the very least.

$$T = T_a + T_L$$

$$= 0.72 + 0.13 = 0.85\ [\mathrm{N{\cdot}m}]$$

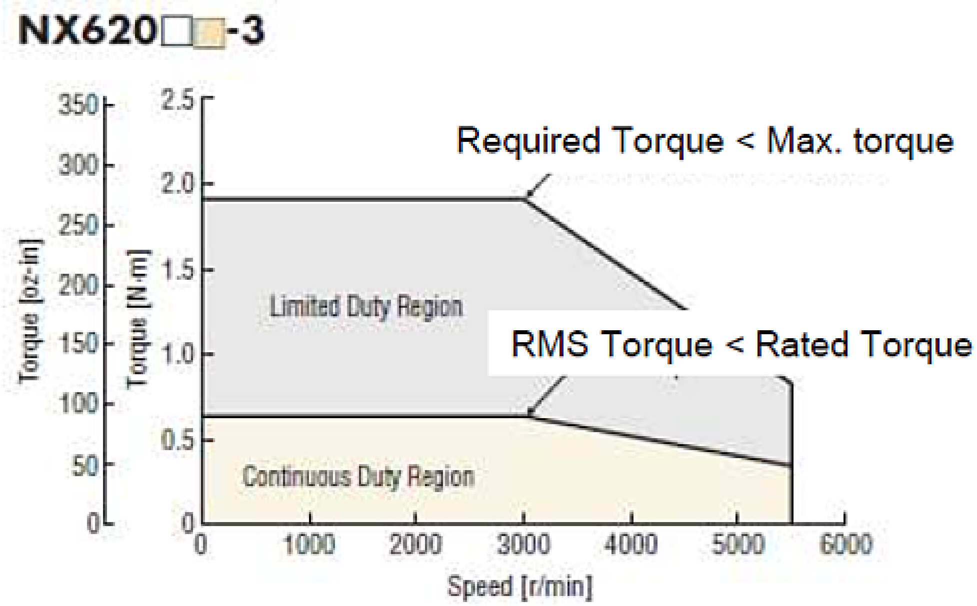
However, this is without a safety factor.  If you use a safety factor of 2, then we will need a stepper motor that can output 1.7 Nm torque at about 1200 RPM; depending on the acceleration/deceleration rates.  Safety factors are determined based on the accuracy of the variables.

For stepper motors, it's important not to use the "maximum holding torque" specification to select a motor since that is measured at close to zero speed.  Since the torque produced by a stepper motor decreases as speed increases, you will need to look at the speed-torque curve to determine if the stepper motor will work at that speed or not.  Typically, selecting a motor based on the total required torque and max required speed is a safe bet even though the motor may not need that torque at its max speed.  A little bit of oversizing, when done properly, can extend life or improve performance of the motor.




## Step 6:  RMS Torque

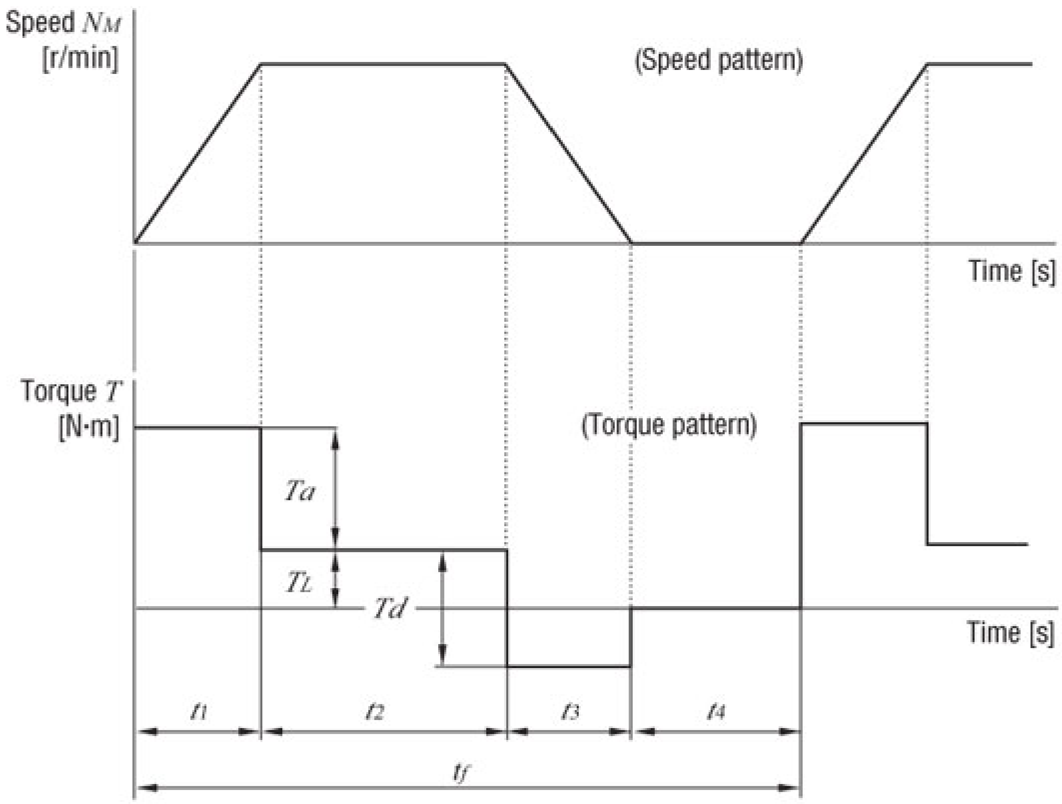
For servo motors, there is another calculation that must be done, which is RMS torque.  Root mean squared torque, or RMS torque, refers to an average value of torque that considers all the varying torque values used during operation as well as the time duration each torque value is needed.  RMS torque is used to determine if the motor is properly sized to avoid thermal overload.




For servo motors, the required torque must be below the motor's peak torque, and the RMS torque must be below the motor's rated torque. Since peak torque requires a high level of motor current, it cannot be sustained continuously without overheating the motor.

Let's now look at the equation for RMS torque and visualize the variables in a motion profile pattern.

$$T_{rms} = \sqrt{\frac{(T_a + T_L)^2 \cdot t_1 + T_L^2 \cdot t_2 + (T_d - T_L)^2 \cdot t_3}{t_f}}$$




| TIP: More about RMS torque |
|---|
| For more information about RMS torque, here's a good article from Linear Motion Tips (Design World), **Why RMS torque is important for motor sizing**. |

For this application, we require a motor with high positioning (stop) accuracy, which would be either stepper motors or servo motors.

For a **stepper motor**, we would need to meet or exceed the following requirements.

*Load Inertia = 5.56 × 10−4 [kg·m2]*

*Total Torque = 0.85 [N·m]**

*Maximum Speed = 1200 [ r/min ]*

For a **servo motor**, we would need to meet or exceed the following requirements.

*Load Inertia = 5.56 × 10−4 [kg·m2]*

*Total Torque = 0.85 [N·m]**

*RMS Torque = 0.24 [ N·m ]*

*Maximum Speed = 1200 [ r/min ]*

*Calculated torque does not include safety factor.

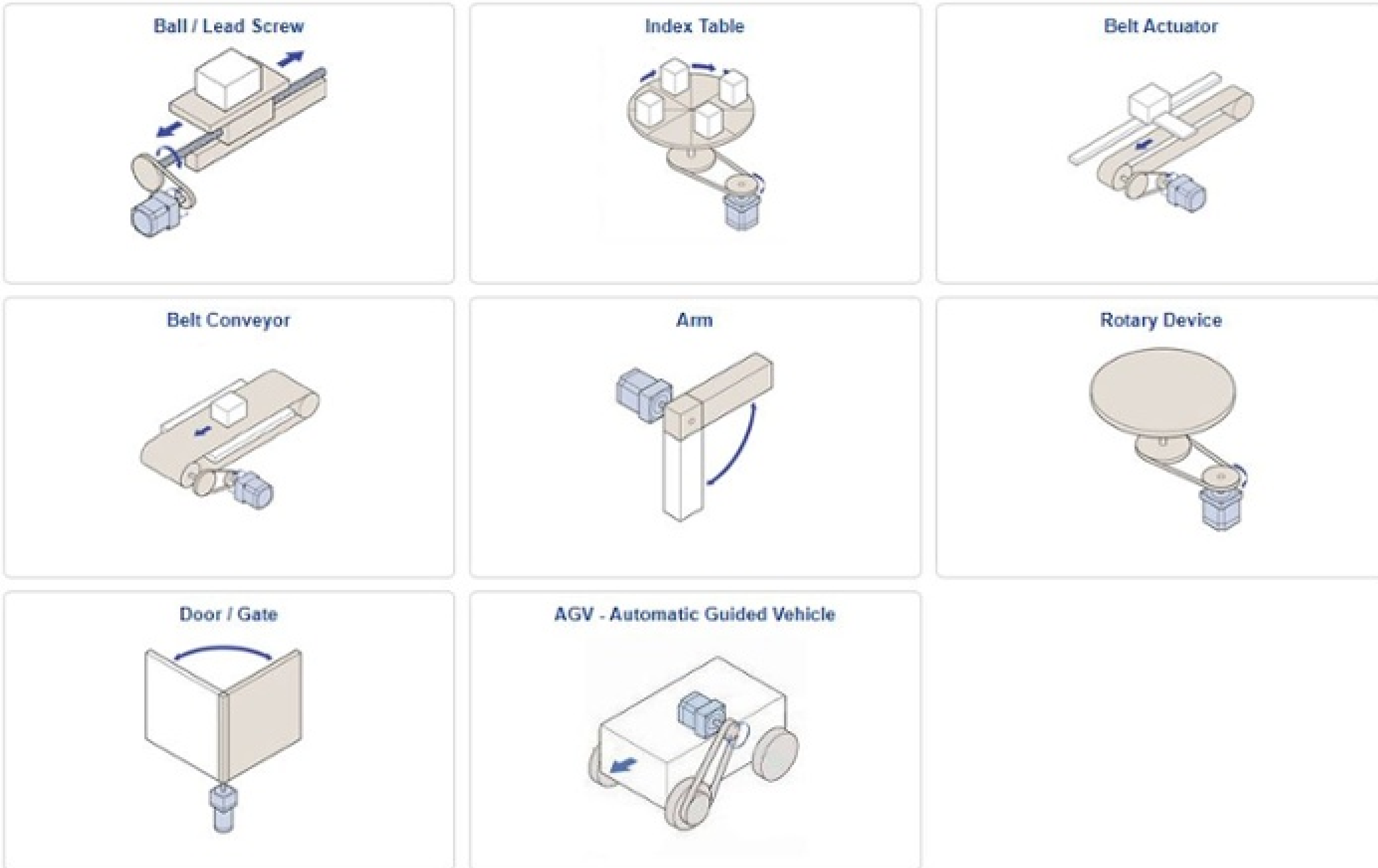
With a required torque, load inertia, and a required speed, we have sufficient information for motor selection. However, there is another important criteria to consider in order to maintain long term life. HINT: it has something to do with bearings. Please subscribe to receive e-mail notifications of new posts.

Learn more about motor sizing calculations

## Is There An Easier Way to Size Motors?

For the most common applications, motor sizing calculators are offered from motor manufacturers where you can simply plug in values to quickly calculate the results. A deeper understanding into motor sizing equations is still necessary for more complex applications.

The thing to remember about motor sizing is that the result is only as good as the data. Make sure the values used for the calculation is as accurate as possible. The more guessing you do, the larger safety factor you'll need to use at the end. Just like in the real world, there will be some unknowns.




Try Our Motor Sizing Calculators

Topics: AC Motors, Stepper Motors, Alphastep Hybrid Control, Linear & Rotary Actuators, Speed Control, Motor Sizing, BLDC Motors, Servo Motors

## Written by Johann Tang

Johann Tang is a Product Specialist at Oriental Motor USA Corp. with over 15 years of knowledge and experience supporting applications of various types of electric motors, gearheads, actuators, drivers, and controllers.

First Name*

Last Name

Email*

Website

Comment*



Submit Comment

Get Updates*

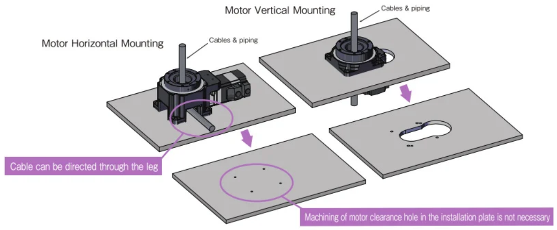
E-mail

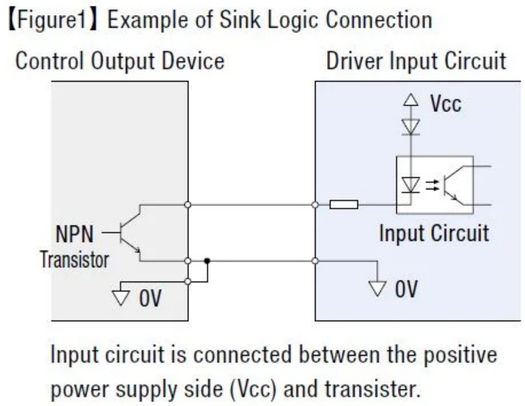
Subscribe

Recent Popular Categories

Flexible Configurations For Hollow Rotary Actuators

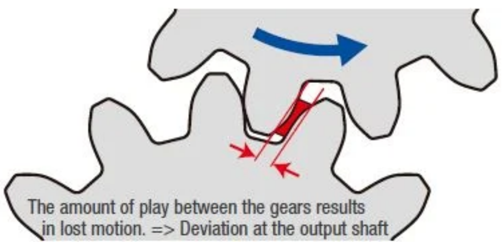
posted at May 21, 2020



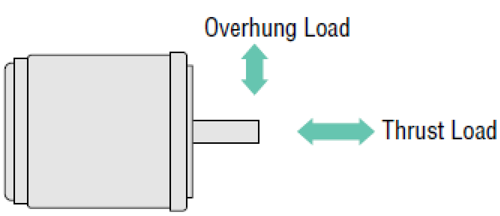

## Control Basics: The Difference Between Sink and Source Logic

posted at Apr 30, 2020



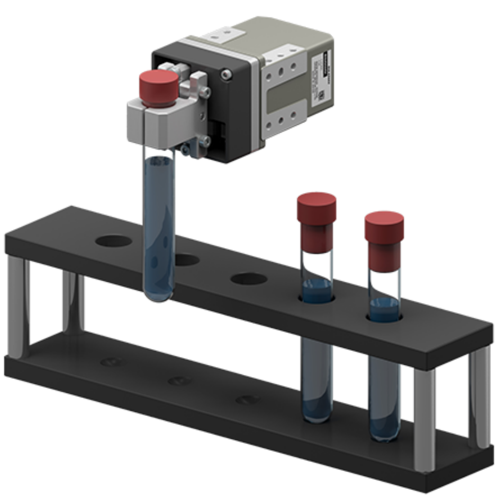

## Gear Basics: Backlash vs Lost Motion

posted at Apr 29, 2020




## Motor Sizing Basics Part 4 - Radial Load and Axial Load

posted at Mar 31, 2020



## The Proper Way to Use a Gripper

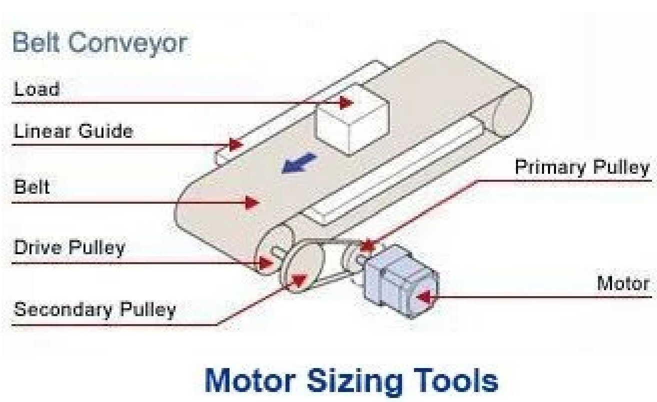
posted at Mar 5, 2020

## Posts by Topic



## Recent Posts






## About Us

Oriental Motor offers an extensive product line-up of about 50,000 different products that provide the optimal motion system. For over a century we have concentrated on technological advancement and product design improvement. This emphasis is evident in the sophisticated devices that we market today. Oriental Motor's sales and service network is international, with offices throughout North America, Europe and Asia.

## More Links

- Home
- About Us
- Contact Us

## Contact Us

1-800-GO-VEXTA (468-3982)

sales@orientalmotor.com

570 Alaska Avenue, Torrance CA 90503