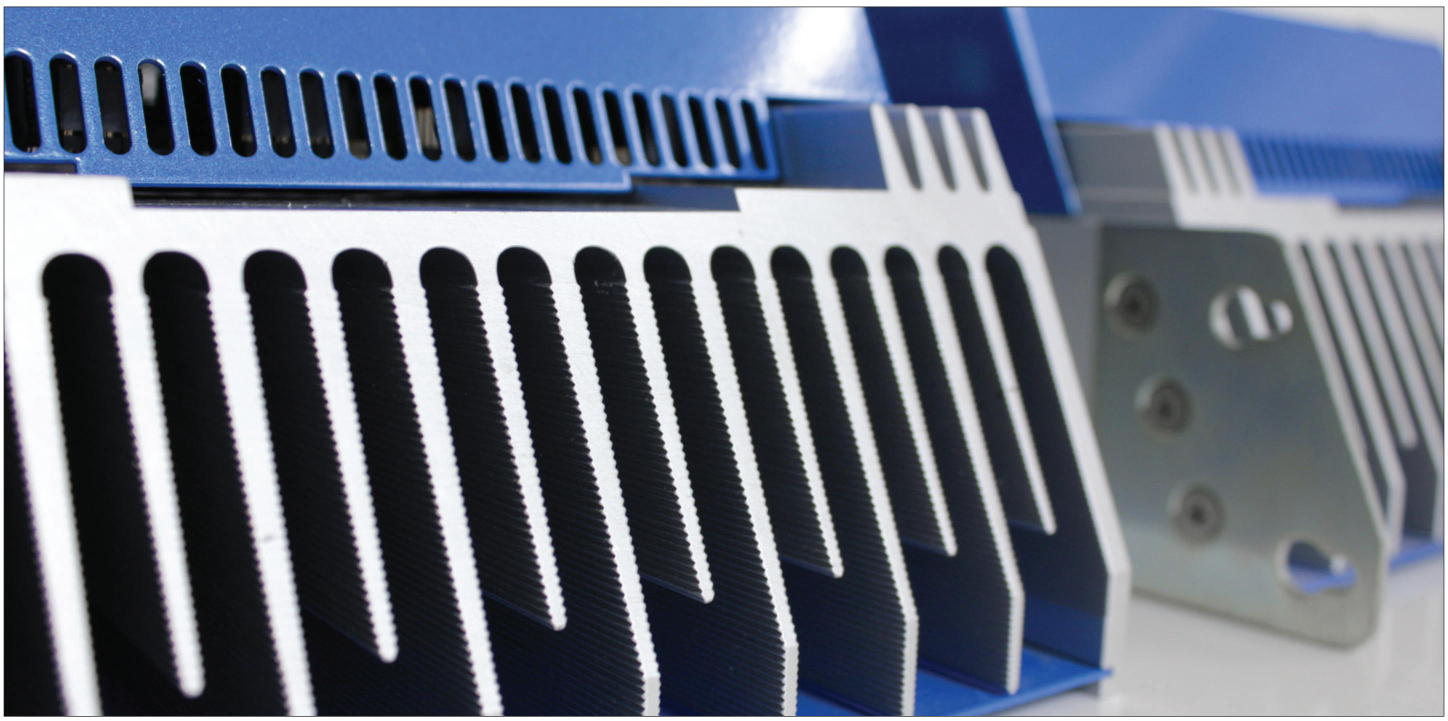
WHITE PAPER

How to Size a Linear Drive for Precision Positioning Applications

Reap the benefits of low noise and high precision with a properly sized linear drive system.



If you design motion control systems, chances are you've worked with pulse width modulated (PWM) drives. Thanks to their stability, availability and familiarity, PWM drives are the default choice in most day-to-day motion control jobs. But PWM drives tend to be noisy, producing a degree of electromagnetic interference (EMI) that makes them less than ideal in some high-fidelity motion applications.

These noise-sensitive applications include advanced inspection and metrology tools used by the semiconductor industry as well as medical imaging and diagnostic systems. And that's where linear drives come into play. Rather than the continuous voltage switching that defines PWM, linear drives scale an input voltage to arrive at a desired current or voltage output.

This constant gain approach results in fast, accurate current loops and also eliminates any deadband at the drive's zero crossing, giving linear drives an edge in high-precision motion control applications.

The price you'll pay for the improved precision will mostly come in the form of heat. Linear drives typically maintain small amounts of power inside the drive circuits, increasing heat. Excess voltage not needed by the motor is also dissipated as heat. To manage these thermal conditions while meeting the application requirements, it's crucially important that you size linear drives correctly. Here's how:

1. Define System Requirements

Right-sizing a linear drive to match a motion control application is a multi-step process due to the many factors that influence system behavior. The most important system variables from a sizing standpoint are:

- Peak motor velocity in RPM
- Peak motor torque or force
- Average velocity and torque values

Load characteristics and friction effects are implicit in the motor, torque and force requirements. You'll also need to take the motion profile into consideration when calculating both peak and average torque requirements. For example, a trapezoidal profile requires constant torque until peak velocity is reached. In contrast, an S-curve or parabolic profile requires gradually less torque as the move sequence approaches peak velocity. To obtain actual application values, torque must be calculated for each motion profile that will be executed—because average torque must be known in order to determine average power dissipation.

2. Select a Motor and Drive

Once the required motion parameters are defined, it is time to make the initial motor and drive selection. First, choose a motor family capable of satisfying peak torque and speed requirements. Next, calculate the required voltage and current for each motor in the system and look for a matching drive that can handle these voltage and current values. Note that the required voltage is based on the voltage constant (Ke) and peak speed, while the required current is based on the torque constant (Kt), peak torque and resistive losses. Consult the lookup chart or specification sheet of the linear drive being considered to see if there is a match. If not, either another motor or a different drive will need to be selected.

Consider the following example. From the desired motion profile, we know that:

Peak velocity = 400 mm/s (0.4 m/s)
Peak torque = 1344 N
Stage mass = 280 kg

Motor Properties:

Voltage constant (Ke) = 163.5 m/s/V
Torque constant (Kt) = 141.6 N/A
Winding resistance (r) = 9.5 Ω

Voltage and Current Requirements:

Peak current required (I_{peak}) = Peak torque/Kt

I_{peak} = 1344 N/141.6 N/A = 9.5 A

Peak voltage (V_{peak}) = (Ke × peak velocity) + (winding resistance (r) × I_{peak}) + drive overhead

(10 V safety margin for the Trust Automation TA330/333 linear drive used in this example)

V_{peak} = (163.5 m/s/V × 0.4 m) + (9.5 Ω × 9.5 A) + 10 V = 165.6 V

Bi-polar power supply requirement = 1/2 V_{peak} = 0.5 × 165.6 V = 82.8 V

In this example, the calculated voltage and current values of 165.6 V and 9.5 A are within the TA333's capability. (TA333 = 25 A and 200 V; TA330 = 18 A and 150 V). The voltage is slightly higher than the TA330's capability (150 V), so the TA333 is necessary to meet the 165.6 V requirement. Note that this calculation exercise can be done to check the suitability of any linear drive.

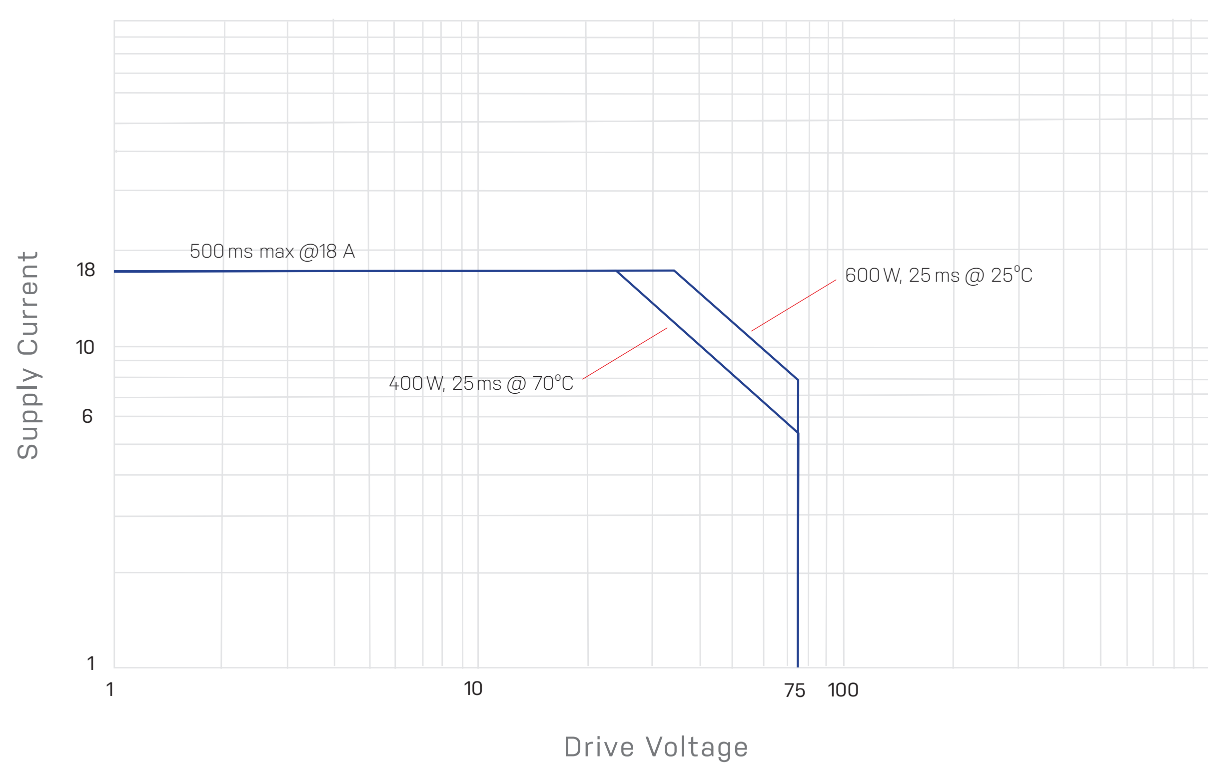
3. Determine Safe Operating Area (SOA)

Once you've made the initial linear drive selection, the safe operating area (SOA) for the application must be calculated to ensure that the power does not surpass the drive's capacity.

Although certain linear drives feature a reactive safety capability, if the SOA is exceeded significantly and quickly, the drive may not be able to shut down in time to prevent damage. Basically, a linear drive acts as a large variable resistor in the supply-motor-drive circuit. Supply voltage is divided between the motor and drive with the current in series, using a pair of power devices and the motor. It is important to be aware of two of the most common danger conditions—stalls and dynamic breaking and deceleration.

Following are examples and calculations of these two danger scenarios, one involving a stalled motor and the other illustrating a dynamic stopping motion. Note that the TA330 and TA333 used in these examples calculate wattage per power device. At least two power devices are on at any time, so the individual worst case wattage is half the total wattage.

Safe Operating Area (SOA)



Danger Scenario I—Stalled Motor

Consider that the motor is stalled and pushing against a hard stop while the controller is commanding 9.5 A. Known values are as follows:

V_{supply} = 192 V (total supply voltage)

$I_{command}$ = 9.5 A (commanded current)

Winding resistance = 9.5 Ω (motor impedance)

Temperature = 30°C (heatsink temperature)

Calculated Values:

V_{motor} = 90.3 V (motor voltage = 9.5 A × 9.5 Ω)

V_{drive} = 101.7 V (remaining voltage = 192 V − 90.3 V)

W_{drive} = 966.6 W (total wattage the drive must dissipate)

W per device = 483.3 W (wattage for use in SOA chart; half of total wattage)

According to the TA333 SOA chart that covers wattage, time and temperature, 483.3 W at 30°C is within the continuous operation zone. Be sure to ask your linear drive manufacturer for the SOA chart or spec sheet that corresponds to the drive you are considering.

Danger Scenario II—Dynamic Stopping

Whenever motion is involved, wattage calculations become much more complex. This complexity is due to the kinetic energy involved in moving the load. When the controller sends a command to stop moving, kinetic energy must be dissipated. In a traditional PWM drive setup, kinetic energy is pushed back onto the power supply bus and a shunt regulator is typically used to dissipate this energy. With a linear drive, the kinetic energy is absorbed by the drive itself, but must be dissipated as heat. This energy must be added to the energy required by the drive to stop all motion.

The exact amount of kinetic energy to be absorbed is challenging to calculate, because system efficiency and friction are large variables that must be considered. For example, an ultra-low friction air bearing stage may retain close to 100 percent of this energy, while a high friction lead screw stage might only retain 5 percent of this energy.

In the following example, linear deceleration is assumed. Average kinetic energy over the stopping time is used in these calculations and is applied at the point when the motor stops, but the command current is still going:

Kinetic energy (KE) = 0.5 × mv^2 (KE is expressed in joules)

Wattage = (KE/2)/time (assuming linear deceleration)

Adjusted wattage = wattage × friction factor

Units:

m = mass (Kg)

v = velocity (m/s)

KE units = joules (J)

t = time to stop motion

Friction factor % = estimated energy lost to friction (ff)

Known Values:

Mass = 280 Kg

Velocity = 0.4 m/s

Time = 0.1 s

ff = 90%

Calculated Values:

KE = 0.5 × 280 Kg × $(0.4\ m/s)^2$ = 22.4 J

W = (22.4 J/2)/0.1 s = 112 W

W adjusted = 90% × 224 W = 100.8 W

The kinetic energy value should now be added to the stalled wattage equation to obtain a rough estimate of the wattage the drive will need to dissipate when stopping. This energy must be added to the individual power device wattage because it is not shared energy. From the stalled motor calculations in the previous example, we take the 483.3 W and add the KE wattage of 100.8 W. The result is a 584.1 W thermal load on the drive. Not all linear drives are designed to measure kinetic energy. Nevertheless, it is extremely important for system designers to consider these calculations when setting up a motion system.

4. Calculate Continuous Dissipation

As the final step in choosing a correctly sized linear drive, it is important to calculate the continuous operating limits to ensure that average wattage is not exceeded, which could damage the drive and degrade overall system performance. Keep in mind that average velocity and torque are calculated in relation to time. To keep things simple, assume a trapezoidal motion profile and use half the torque and velocity during acceleration and deceleration.

Using these values, generate a timetable with the system's torque and velocity for the move profile. Be sure to include all cycle times and dwell times. Multiply the time value by the torque value and sum all steps, then divide by the total time for the average torque value. Repeat with velocity to obtain the average. Next, use these average numbers to calculate wattage in the same manner as the first example described previously.

Average current required (I) = Average torque/Kt

Average voltage required (V) = (Ke × average velocity) + (winding resistance × average current required)

Average wattage dissipated = (Supply voltage – average voltage) × average current

Example:
Supply voltage = 192 V
Average torque = 247.1 N
Average velocity = 0.18 m/s

Using the Selected Motor Properties:
Voltage constant (Ke) = 163.5 m/s/V
Torque constant (Kt) = 141.6 N/A
Winding resistance (r) = 9.5 Ω

Average current required (I) = Average torque/Kt

Average voltage required (V) = (Ke × average velocity) + (winding resistance × average current required)

Motor I = 247.1 N/141.6 N/A = 1.74 A

Motor V = (163.5 × 0.18) + (9.5 Ω × 1.74 A) = 46.3 V

Total drive W = (192 – 46.3) × 1.74 = 254.2 W

The final step is to verify that the average heatsink wattage does not exceed 400 W with the heatsink at 20°C (for the TA330 and TA333 linear drives discussed here). Calculated results must be evaluated against the drive's SOA chart. In the example used here, calculated peak wattage is 584.1 W for a duration of 0.1 s (100 ms).

According to the TA330 SOA chart, 584.1 W in continuous operation corresponds with a heatsink temperature up to 29°C. At 30-34°C, the controller would allow 61 ms prior to generating a fault. Note that the allowed time decreases as temperature rises. Therefore, if the heatsink temperature is allowed to climb above 29°C, driving for 100 ms, the drive could be damaged.

Studying the TA333 SOA chart, 584.1 W in continuous operation corresponds with a heatsink temperature up to 49°C. At 50-54°C, the controller would allow 84 ms prior to generating a fault. In this case, if the heatsink temperature is allowed to climb above 49°C, the drive could be damaged.

The tips and calculations described here are intended to help you make an informed choice when selecting a linear drive. Once the actual system is up and running, however, these values should be analyzed again to optimize drive performance. To learn how linear drives can improve positioning in your next motion control application, visit **www.trustautomation.com**.