Linear Sizing Calculations

Move Profile

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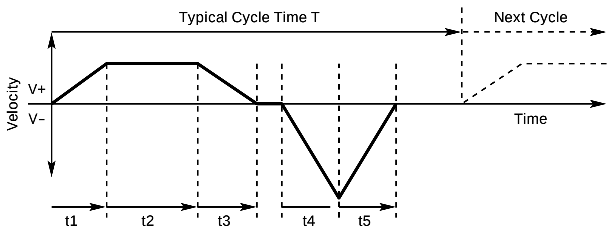
PRODUCTIVITY THROUGH TECHNOLOGY

Rotary and linear actuator selection begins with the calculation of speed, thrust and torque requirements. In order to determine the torque required, the acceleration of the mass being moved must be calculated. A **"move profile",** or a **plot of load velocity vs. time,** is sketched in order to simplify the **peak acceleration** and **peak velocity** calculations.

Typical Machine Cycle



(1) Total distance, $d_{tot} = v_{MAX}\left[\frac{t_1}{2} + t_2 + \frac{t_3}{2}\right]$

(2) Max velocity, $v_{MAX} = \dfrac{d_{tot}}{\left(\frac{t_1 + t_3}{2}\right) + t_2}$

(3) Acceleration, $a = \dfrac{v_{MAX}}{t_{ACCEL}}$

The figure above is an example of a typical machine cycle, and is made up of two Move Profiles; the first is an example of **a trapezoidal profile,** while the second is a **triangular profile.** The horizontal axis represents time and the vertical axis represents velocity (linear or rotary). The load accelerates for a time (t_1), has a constant velocity or slew section (t_2), and decelerates to a stop (t_3). There it dwells for a time, accelerates in the negative direction (t_4), and decelerates back to a stop (t_5) without a slew region. The equations needed to calculate Peak Velocity and Acceleration for a general trapezoidal profile are shown in the figure. A triangular profile can be thought of as a trapezoidal profile where $t_2 = 0$.

The Move Profile sketch contains some important information:

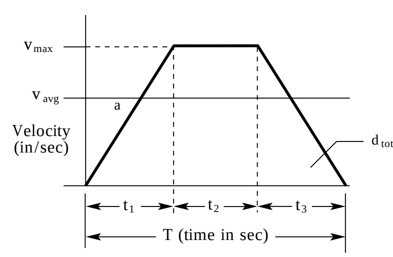
- **Peak acceleration** is the steepest slope on the curve, in this case during t_4 or t_5.
- **Maximum velocity** is at the highest or lowest point over the entire curve, here at the peak between t_4 and t_5.
- **Distance** is equal to the area under the curve. Area above the time axis represents distance covered in the positive direction, while negative distance falls below this axis. The distance equation (1) is just a sum of the areas of two triangles and a rectangle.

Trapezoidal and Triangular Profiles

A couple of assumptions can greatly simplify the general equations. For the Trapezoidal profile we assume $t_1=t_2=t_3$, and for the Triangular we assume $t_3=t_4$. Substituting these assumptions into equations (2) and (3) yields the equations shown in the figure below.

For a given distance (or area), a triangular profile requires lower acceleration than the trapezoidal profile. This results in a lower thrust requirement, and in turn, a smaller motor. On the other hand, the triangular profile's peak speed is greater than the trapezoidal, so for applications where the motor speed is a limiting factor, a trapezoidal profile is usually a better choice.

Trapezoidal Move Profile



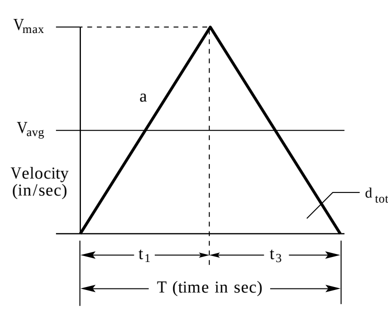
$v_{AVE} = \dfrac{d_{tot}}{t_{tot}}$

$t_1 = t_2 = t_3 = \dfrac{t_{tot}}{3}$

$v_{MAX} = 1.5\,\dfrac{d_{tot}}{t_{tot}} = 1.5\,v_{AVE}$

$a = 4.5\,\dfrac{d_{tot}}{(t_{tot})^2}$

Triangular Move Profile



$v_{AVE} = \dfrac{d_{tot}}{t_{tot}}$

$t_1 = t_3 = \dfrac{t_{tot}}{2}$ $\quad t_2 = 0$

$v_{MAX} = \dfrac{2d_{tot}}{t_{tot}} = 2\,v_{AVE}$

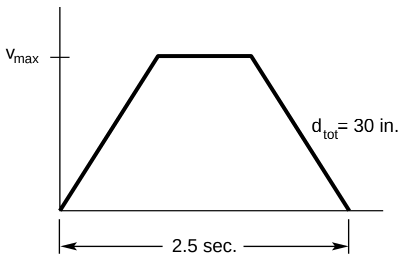
$a = \dfrac{4d_{tot}}{(t_{tot})^2} = \dfrac{2v_{MAX}}{t_{tot}}$

Move Profile

Example 1

Calculate the peak acceleration and velocity for an object that needs to move 30 inches in 2.5 seconds. Assume a Trapezoidal Profile.

Solution



$$v_{AVE} = \frac{30\text{ in}}{2.5\text{ sec}} = 12\text{ in/sec}$$

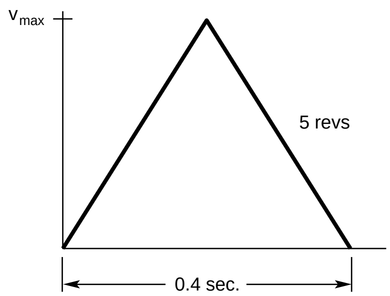
$$v_{MAX} = 1.5\,\frac{d_{tot}}{t_{tot}} = 18\text{ in/sec}$$

$$a = 4.5\,\frac{d_{tot}}{(t_{tot})^2} = 21.6\text{ in/sec}^2$$

Example 2

Calculate, in radians/sec, the peak acceleration and velocity for an cylinder that needs to move 5 revolutions in 0.4 seconds. Assume a Triangular Profile.

Solution



$$d_{tot} = 5\text{ revs} \times \frac{2\pi\text{ rad}}{\text{rev}} = 31.42\text{ rad}$$

$$v_{AVE} = \frac{31.42\text{ rad in}}{0.4\text{ sec}} = 78.55\,\frac{\text{rad}}{\text{sec}}$$

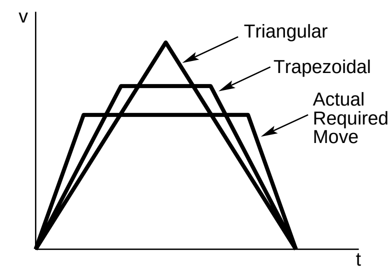
$$v_{MAX} = 2\,v_{AVE} = 157.1\,\frac{\text{rad}}{\text{sec}}$$

$$a = 4\,\frac{d_{tot}}{T^2} = 785.5\,\frac{\text{rad}}{\text{sec}^2}$$

Example 3

This is an example of a case when triangular and trapezoidal move profiles are not adequate approximations. Assume a maximum actuator speed is 6 inches/sec. Sketch a move profile that will complete a 10 inch move in 2 seconds. What is the minimum allowable acceleration rate in inches/sec^2?

Solution



Triangular

$$v_{AVE} = \frac{10\text{ in}}{2\text{ sec}} = 5\text{ in/sec}$$

$v_{MAX} = 2 \times v_{AVE} = 10$ in/sec ($v_{MAX} > 6$ in/sec – too fast)

Trapezoidal

$v_{MAX} = 1.5 \times v_{AVE} = 7.5$ in/sec ($v_{MAX} > 6$ in/sec – too fast)

These are too fast, so we need to find t_1 as follows:

Required Profile

$$d_{tot} = v_{MAX}\left(\frac{(t_1 + t_3)}{2} + t_2\right)$$

substitute $(t_1 + t_3) = t_{tot} - t_2$

$$\frac{d}{v_{MAX}} = \left(\frac{(t_{tot} - t_2)}{2}\right) + t_2 = \frac{t_{tot}}{2} + \frac{t_2}{2}$$

solving for t_2,

$$t_2 = \left(\frac{d_{tot}}{v_{MAX}} - \frac{t_{tot}}{2}\right) \times 2 = \left(\frac{10\text{ in}}{6\text{ in/sec}} - \frac{2\text{ sec}}{2}\right) \times 2$$

$$t_2 = 1.33\text{ sec}$$

Now assume $t_1 = t_3$, so

$t_1 = (t_{tot} - t_2)/2 = 0.33$ sec.

Finally, calculate acceleration

$$a = \frac{v_{MAX}}{t_1} = \frac{6\text{ in/sec}}{0.33\text{ sec}} = 18\,\frac{\text{in}}{\text{sec}^2}$$