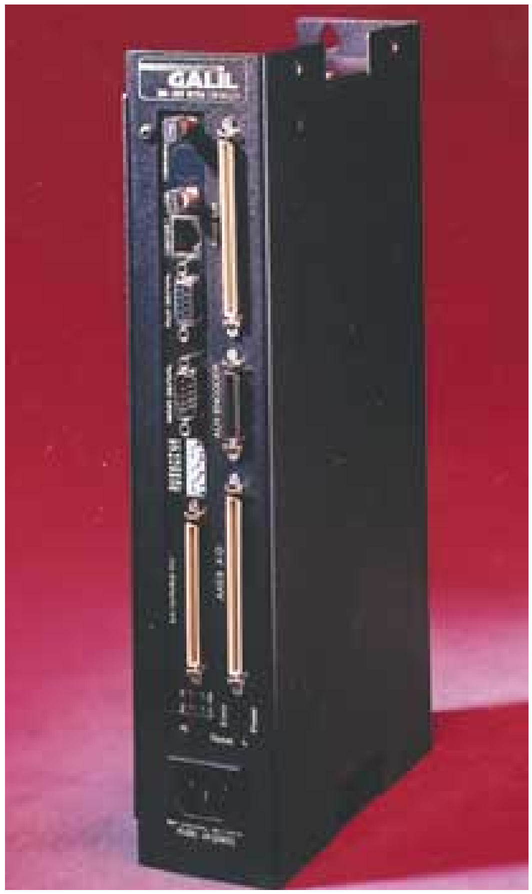
MACHINE DESIGN

 Machine Design (ISSN 0024-9114) is published by Penton Media, Inc., 1100 Superior Ave., Cleveland, OH 44114-2543.

Editorial content is indexed in the Applied Science Technology Index, the Engineering Index, SciSearch and Research Alert. Microfilm copies available from University Microfilms, Ann Arbor, MI 48106. Fax (313) 665-5022.

Penton

Optimal Velocity
For Start/Stop Systems



Galil Motion Control's DMC-2000 controller communicates with other computers over the Ethernet using a built-in feature called Multimaster. The unit also controls a variety of I/O devices, both directly and through the Modbus protocol. Communication over Ethernet requires less wire and lets the DMC-2000 access hundreds of connected I/O devices.

Maximizing a motion-control system's throughput often involves repeating a particular move as rapidly as possible without overheating the motor. The question to explore then regards the selection of a velocity profile. For example, when a motor must rotate a specific angle and stop within t sec, what is the shape of the velocity curve that will execute the move while minimizing power dissipation in the motor?

Optimal velocity

It turns out that the optimal velocity profile is a parabola, as shown in the figure *Parabolic velocity*. Curve A shows the velocity and curve B, the acceleration. The energy dissipation (E, *joules*) in the motor for a single step is:

$$E = \frac{12 R J^2 \Theta^2}{k_t^2 t^3}$$

where: R = armature resistance, ohms; J = moment of inertia, $kg.m^2$; θ = step size, degrees; k_t = torque constant of motor, Nm/A; and t = motion time, sec.

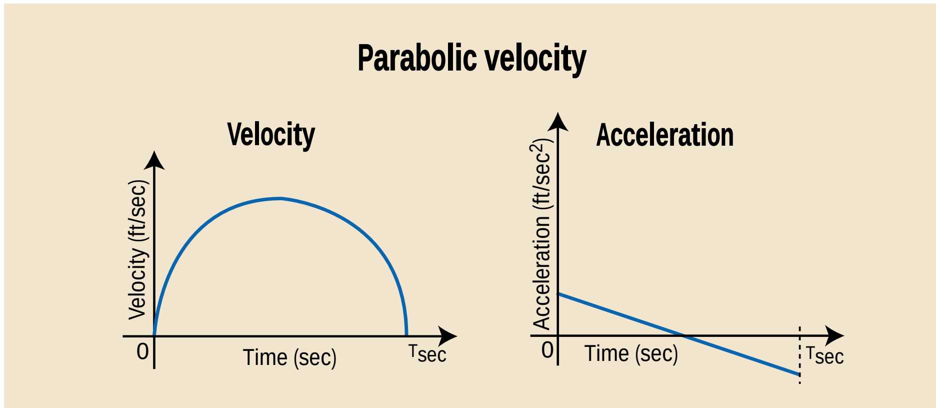
Although parabolic velocity profiles are optimal, they are not commonly used, principally because parabolic curves require complex functions to generate. Other factors that discourage using them include amplifiers with a large current requirement, and unwanted vibrations caused by these currents at the beginning and end of the motion.

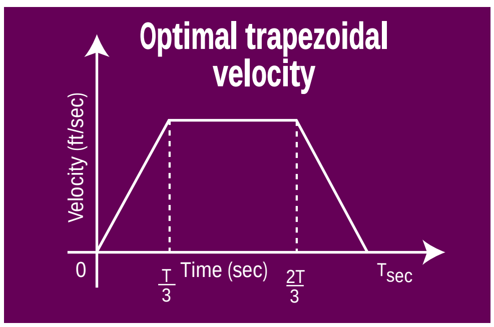
Consider a trapezoidal velocity as an alternative, although it has less than an optimal profile. But the issue is, what is the best trapezoidal velocity profile, and what is the relative efficiency of a trapezoidal curve compared with a parabola?

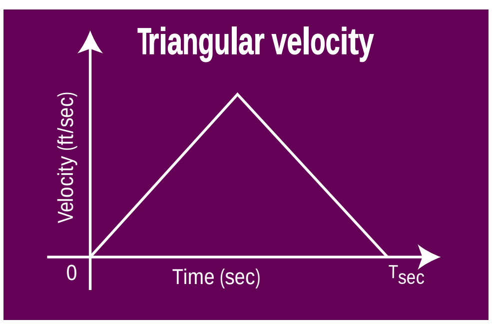
The answer is that the optimal trapezoid is one where all three intervals of acceleration, slew, and deceleration are equal, as shown in *Optimal trapezoidal velocity*. The energy dissipation per step under the trapezoidal velocity is:

$$E = \frac{13.5 R J^2 \Theta^2}{k_t^2 t^3}$$

Comparing equations shows that the power dissipation is increased by the ratio of 13.5/12 or 12.5%. Another widely used velocity profile







is the triangular shape as shown in *Triangular velocity*. Analyzing this case reveals that the energy dissipation is:

$$E = \frac{16 R J^2 \Theta^2}{k_t^2 t^3}$$

or 33% more than a parabolic profile.

The use of these results is illustrated by the following example.

A motor must turn one revolution in 60 msec and repeat the move 10 times/sec. Substituting parameters in equation one, determine the temperature rise in the motor under the three velocity profiles. Start the analysis with the parabolic profile. The energy dissipation per step is:

$$E = \frac{12 R J^2 \Theta^2}{k_t^2 t^3}$$

$$E = \frac{(12)(2.5)(10^{-4})(2\pi)^2}{(0.10)^2\ (0.06)^2}$$

$$E = 5.5\, joules$$

where $J = 10^{-4} kg.m^2$, $\Theta = 2\pi$ rad, $k_t = 0.1$ Nm/A, $R = 2.5\Omega$, and $t = 0.06$ sec.

This results in the power dissipation

$P = E \times f = 55$ W,

and produces a temperature rise of

$Q = R_{th} P$

where $f = 10$ steps/sec (repetition rate) and $R_{th} = 1.5°$ C/W (motor thermal resistance).

In the second case, using the same equation as the parabolic profile, the trapezoidal velocity

$E = 6.2$ *joules*,

and produces a temperature rise of 93°C.

Finally, the triangular profile results in an energy dissipation of 7.33 *joules* and a temperature rise of 110°C. As expected, the parabolic profile generates the least power dissipation and heat rise. ■

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