

# Mastering motion profiles to boost precision and throughput

10 March 2026

Calculating an application's motion profile is crucial to optimising its performance. While modern control architecture can create profiles according to high-level limits, understanding the underlying mathematics allows engineers to improve precision and throughput. Selecting between techniques such as trapezoidal, S-curve, and sinusoidal motion profiles, and tuning them accordingly, are key to achieving the right balance of motion stability and speed.

*Gerard Bush, engineer at motion specialist INMOCO, explains what you need to know.*

A motion profile is a plan that represents how a motor axis moves over time, defining its speed, acceleration, and position. Although this applies to the changing state of any motor, a motion profile is typically planned within a closed-loop, feedback-based system where precise motor control is important to the process. As a result, motion profiling is key to the set-up of servo and stepper motors.

Today, modern drives and controllers can automate various aspects of motion profile generation, based on specifying high-level trajectory limits such as distance and speed, to compute the detailed trajectory. However, this approach doesn't remove the need to consider the mathematics behind a machine's motion profiles. Left to the controller alone, there's a risk of introducing positional errors, overshoot, vibration, or increased settling time, based on the assumptions of the controller's pre-programmed algorithms.

Instead, understanding a machine's motion profile and its constituent parameters can help to optimise performance, speed up commissioning, and maintain long-term stability when installed in the field.

## **Trapezoidal and S-curve profiles**

The most commonly used move is the point-to-point profile, where the load starts from rest, speeds up until it reaches a steady velocity, then slows down so that it comes to a complete stop at the target position. The simple way to achieve this is the trapezoidal profile, so called because of the corresponding shape created by its velocity profile. Comprising three stages, velocity ramps up linearly, remains at a constant level for a defined period, then linearly ramps down.

A trapezoidal velocity profile reaches the target quickly as it changes acceleration instantly, and a triangular motion profile – which removes the constant velocity phase – could achieve this even quicker. However, the limiting factor for both these profiles is the prevalence of jerk – the change of acceleration over time. The effects of jerk can include vibration or oscillation, which diminishes precision by causing positional error or overshoot. Even if jerk is taken into account when planning the motion profile, this will increase the settling time of the motor axis, the period that allows stabilisation, and the result in practical terms is decreased machine throughput. Longer term, the results of jerk can also increase mechanical wear and subsequent maintenance challenges.

To reduce the prospect of jerk, an S-curve motion profile can be introduced, which includes seven distinct phases of motion. These additional motion phases transition between periods of acceleration and non-acceleration, smoothing out the trajectory by decreasing the acceleration rate of change. While trapezoidal profiles are, strictly speaking, faster than S-curve motion profiles, to optimise the performance of the application it's important to consider the extent of acceleration smoothing required to minimise jerk, balancing precision with throughput.

## **Sinusoidal profiles**

For example, in a high-speed pick-and-place application that also has a more stable load, an S-curve can be introduced where the acceleration-smoothing phases are shorter, between 5–15% of the time spent accelerating or decelerating, which will reduce smoothness but increase transfer speed. While the S-curve slightly increases the

commanded move time compared to a trapezoidal profile, by lowering end-of-move oscillation it reduces the total effective transfer time.

Alternatively, in cases where jerk needs to be further minimised, for example medical applications with liquid transfers that shouldn't be jostled, it could be appropriate to use an S-curve motion profile without a constant acceleration section. Instead, acceleration and deceleration transitions could be spread as smoothly as possible to maximise stability and lower jerk.

Making this smoother S-curve even gentler, we move to the sinusoidal profile. Designed to a sine wave shape, the sinusoidal profile is characterised by acceleration and deceleration ramps that transition with no abrupt changes in slope. While a standard S-curve has linear acceleration ramps, a sinusoidal profile has a smooth, continual curve, which gradually ramps acceleration from zero to its peak and back again, resulting in lower jerk.

### **Optimising the motion profile**

Determining how much S-curve is required for the application, or even whether a sinusoidal profile might be necessary, is the skill of optimising the motion profile. This is particularly the case where automated motion profiling systems can limit capabilities, such as restricting changes on-the-fly, where changes in the motion profile might be needed in reaction to feedback, or not allowing asymmetric profiles. Balancing jerk with transfer time while dealing with factors such as compliance, friction, and inertia, is complex, particularly as these factors may not be known until commissioning the machine. As a result, tuning the load is often a matter of trial and error.

A further approach to profile generation, and one that is used by CNC machines, is to develop a custom profile that compensates for the exact load and motor characteristics of the system. The calculations of the motion profile are made in advance and stored in a table of motion vectors that can also include data such as feedforward, which adds a command instead of waiting for the axis to react to an error in order to add precision and response speed.

## **Motion engineering**

To develop the optimal motion profile for the application, the hardware platform must allow flexible development. For example, Performance Motion Devices (PMD) provides positioning devices, drives, and multi-axis machine controllers that enable motion development across trapezoidal, S-curve, and sinusoidal profiles. These capabilities are based on C-Motion, PMD's easy to use motion control software library, designed for a wide range of applications in the medical, laboratory, semiconductor, robotic, and industrial sectors.

To develop the motion profiles optimised to your application, involving motion engineering expertise can speed up development and enhance the quality and productivity of the application. INMOCO's engineers can provide guidance on motion profiling, along with specification of motion hardware, to achieve a system that balances the demands of control precision with throughput.

**Image Captions:**



**Image 1:** PMD has three product groups that provide advanced S-curve and trapezoidal profiles, programmable start velocity, and cam capability

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## About INMOCO

Established in 1987, INMOCO now offers an extensive range of motion control equipment including: compact servo amplifiers, position controllers, stepper motors, PLC controllers, linear motors, sensors, electric actuators and gearheads. INMOCO's product portfolio is supported by extensive applications and technical expertise, in addition to customer-specified electro-mechanical development and sub-assembly services; including calibrating and testing in a class 10,000 clean room facility.

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