



Achieve Superior Servo Performance, Quickly, with Auto-Tuning

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Servo systems are well-known for their superior performance in demanding motion applications. When system designers want to wrap candy, polish semiconductor wafers, form an aspirin tablet, or lay thin coatings on a roll of plastic, servos do it faster, smoother, and more accurately than just about any other technology.

Unfortunately, getting the superior performance of servos isn't always easy. For example, servo systems must be "tuned," a process where many parameters are set to values that depend on the particular motor, drive, controller, and mechanical load. Tuning the highest-performing motion systems can be challenging.

In this article we'll discuss tuning: why it's required, how it's done, and what happens when it's not done well. We'll also discuss the process of automatically tuning or "auto-tuning." In the past, auto-tuning was effective for a narrow set of conditions: highly rigid mechanical loads and applications that didn't demand top performance. Today, auto-tuning has improved and the best auto-tuners are better at tuning than most people. The goal of this article is to help you better evaluate servo systems and auto-tuning capabilities so you can select the motion components best suited for your application.

Configuration vs. Tuning

Complex configuration processes are common in industrial equipment. However, for most equipment, configuration involves setting up a controller for length of stroke, the number of motor poles, and other concrete parameters that have easily-understood physical meaning. Part of a servo drive's configuration process fits this description—for example, the resolution of a feedback device or the number of magnetic poles for a given motor. But in servo systems, the feedback loops also must be tuned.

Tuning loop gains is the process of raising the value of those gains as high as possible while maintaining an adequate margin of stability. Raise the gains too high and the system will overshoot and ring; it may even become unstable – a condition where the motor oscillates uncontrollably. Keep the gains too low and you can lose the benefit of servos – the system can be sluggish. *Figure 1* shows the step response of a servo velocity control for three cases.

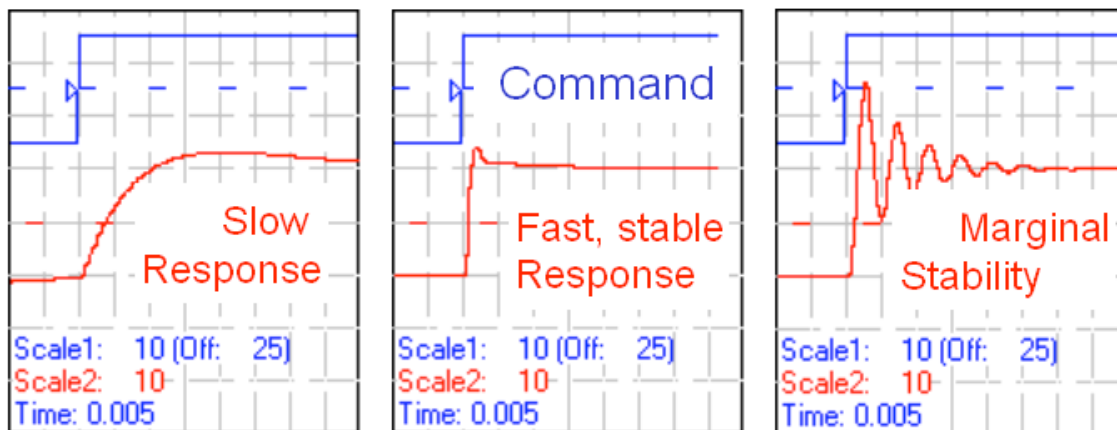


Figure 1. Three ways to tune a servo system.

Case 1. A poorly-tuned velocity controller with gains too low, yielding sluggish performance.

Case 2. A well-tuned velocity controller. Notice the system responds in a few milliseconds with little overshoot.

Case 3. A poorly-tuned velocity controller with gains too high, yielding inadequate margins of stability.

The same thing happens in servo systems, albeit at much higher frequencies. As gear teeth and belts flex in and out, the elements on the end of the drive train seem to almost disappear. As a result, the apparent inertia of a compliant system becomes smaller as frequency increases. Since the effect of inertia is to lower the gain of the whole loop, this phenomenon is destabilizing at high frequencies. At low frequencies the inertia is high, making the loop gain low; at high frequencies the load inertia virtually disappears, causing the loop gain to increase – often dramatically. Worse, the gain variation is difficult to predict. It varies in complicated ways depending on the mechanical resonances of the motor/load mechanism.

It's not possible to fully accommodate the behavior of complicated mechanical structures with a simple loop gain. Instead, various filters must be used to modify the gain and delay as frequency increases. Herein lies the complexity of tuning for optimal performance: it requires the design of multi-pole filters to modify the phase and gain according to the system's mechanics. Of course, it's possible to attain stable operation by simply adjusting a few gains as well as possible and adding perhaps one or two low-pass filters. But this generally results in low gains and sluggish performance. Achieving optimal performance requires a much broader approach: full-frequency tuning.

The effect of compliance can be seen in *Figure 4*. The dashed red line shows an ideal load – that is, one that is perfectly coupled to the motor. As frequency increases, the effect of the inertia is to lower the gain due to the fact that it takes more torque to move mass at a higher frequency. So, the red line declines steadily as frequency increases. A compliant load is shown in purple. It tracks the ideal line well until the frequency nears the point of mechanical resonance. At about 700 Hz, the load starts to “disconnect” from the motor. Above the resonant frequency of 1200 Hz, it disappears and the gain increases well above the ideal load.

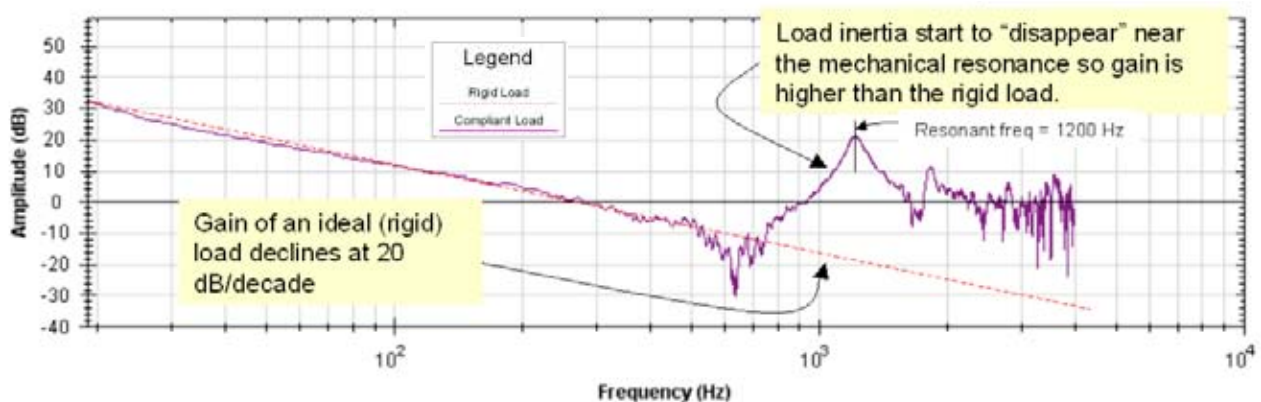


Figure 4. Variation of reaction torque from a typical mechanical system.

We then compared auto-tuning methods on that configuration to several competitors. Some competitors were unable to produce any stable set of tuning parameters, while PST produced tuning superior to all the tested systems with both faster settling times and better margins of stability. For example, *Figure 7* shows the response to a high-acceleration velocity command: compared to the best competitive system, PST cut settling time to less than half and did so with half the overshoot.

In conclusion, tuning can be a complicated process, especially when trying to get high-performance from the compliant load/motor mechanisms commonly seen on modern machines. Auto-tuning can provide superior results quickly, but only when it uses information from the full frequency range of servo operation. Full-frequency auto-tuning algorithms can also support higher-order filter structures than are practical for manual tuning. Full-frequency auto-tuning algorithms together with flexible servo loop filtering can provide outstanding servo performance even for compliant loads, and you don't have to be a servo expert to use them.

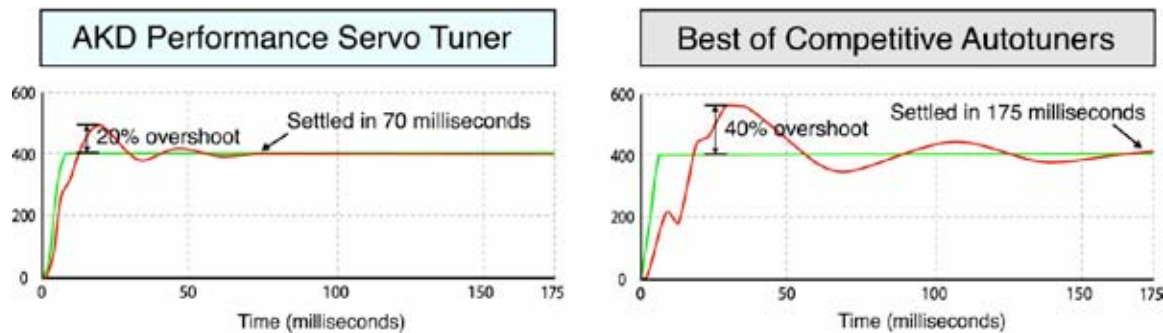


Figure 7. Step response showing superior results of full-frequency auto-tuning: settling time is less than half (75 ms vs. 175 ms) and stability margins are significantly improved (20% vs. 40% overshoot).

ABOUT KOLLMORGEN

Kollmorgen is a leading provider of motion systems and components for machine builders around the globe, with over 70 years of motion control design and application expertise.

Through world-class knowledge in motion, industry-leading quality and deep expertise in linking and integrating standard and custom products, Kollmorgen delivers breakthrough solutions unmatched in performance, reliability and ease-of-use, giving machine builders an irrefutable marketplace advantage.

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