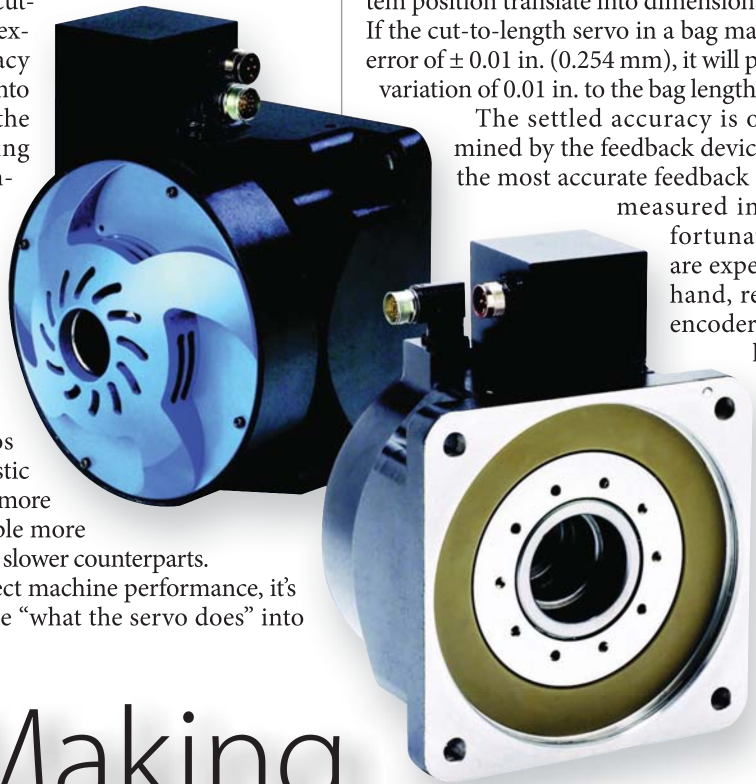
MACHINE Design .com
BY ENGINEERS FOR ENGINEERS

Making SERVOS better

Tricks of the trade let designers optimize servo-driven machines for speed, accuracy, or a quick response.

Today's servo-controlled machines are faster, smaller, and smarter than ever. Even so, machine users demand more and more performance, and this forces designers to keep making improvements. But it can be a challenge to make a machine's servosystem perform better because so many factors come into play: servomotors, the feedback sensor, the servodrives, and the mechanical transmission, to name a few.

Servo performance directly affects the quality of the parts a machine produces and the time it takes that machine to produce them. In cut-to-length applications, for example, positional inaccuracy in a servo often translates into dimensional variation in the parts produced. In printing applications, positional inaccuracy affects registration. Smoothness of the servosystem affects how coating thickness varies in coating machines, and the part finish in polishing applications. Response time affects the rate of production: The fastest servos more quickly cut more plastic bags, print more labels, test more blood samples, and assemble more printer cartridges than their slower counterparts.



While servos clearly affect machine performance, it's not always easy to translate "what the servo does" into "how the machine operates." Designers can evaluate servos with three key measures: accuracy – how close moving parts settle to the commanded position or velocity; response – how fast the motion tracks the command; and robust stability – how reliably the motion tracks the command under various operating conditions.

Accuracy is usually quantified in two ways: settled-position error and cyclical error. Settled accuracy is straightforward. It is the positional accuracy of the servo when it's settled to a commanded position. Errors in the servosystem position translate into dimensional tolerance buildup. If the cut-to-length servo in a bag machine has a position error of ± 0.01 in. (0.254 mm), it will probably contribute a variation of 0.01 in. to the bag length.

The settled accuracy is often largely determined by the feedback device. Sine encoders are the most accurate feedback devices, with errors measured in arc-seconds. Unfortunately, sine encoders are expensive. On the other hand, resolvers and digital encoders are less costly, but have position errors an order of magnitude larger.

Cyclical error, the second type of accuracy measure, is more complicated. When a motor turns at constant speed, position errors translate into an apparent velocity ripple. This ripple repeats every revolution of the motor, hence the term "cyclical." The apparent velocity ripple on the feedback signal feeds the velocity loop, which creates current to compensate for that ripple. Unfortunately, that current creates actual velocity ripple. The result is often a loss of smoothness at speed and more audible noise and motor heat.

Cyclical error is cured with higher-accuracy feedback devices. Sine encoders have so little cyclical error that they often produce no measurable effects; the same cannot always be said of resolvers and digital encoders. The key for machine designers is in selecting the right feedback device for each axis of motion. The best starting point is a motor family such as **Kollmorgen's** AKM™ servomotor, with a wide range of feedback options.

The mechanical transmission also can contribute to inaccuracies. The reason is most machines rely on motor feedback as the primary position signal. If a motor connects to the load through a gearbox, the gearbox positional error will make the motor feedback signal vary from the load position.

Transmission components such as leadscrews, gearboxes, and belts and pulleys all contribute error between the motor and the load. Many of these problems can be adequately addressed by selecting high-quality transmission components. However, designers can look at two other solutions for machines that demand the highest accuracy. First, a secondary feedback device can be placed on the load side of the transmission. For example, a linear glass scale can be added to a screw-driven gantry to eliminate accuracy problems in the screw. The motor-feedback device can still be used to improve performance if the servodrive supports "dual loop," a configuration in which both motor and load feedback are used simultaneously. The need for dual loop (as opposed to using only the load position for feedback) is created because the mechanical compliance between motor and load can severely limit the servo performance when the only feedback comes from a load-side position sensor.

While dual loop solves many problems caused by load inaccuracy, the ultimate solution is a "direct-drive" system, which eliminates the transmission altogether. In direct-drive systems, the motor directly drives the load. The accuracy of direct-drive systems is a factor of 10 better than that of traditional systems; audible noise can fall by 40 dB. Other measures such as servoresponse, acceleration rates, and reliability also can improve dramatically. For the most-demanding servo applications, direct drive is the final step of evolution for the mechanical design.

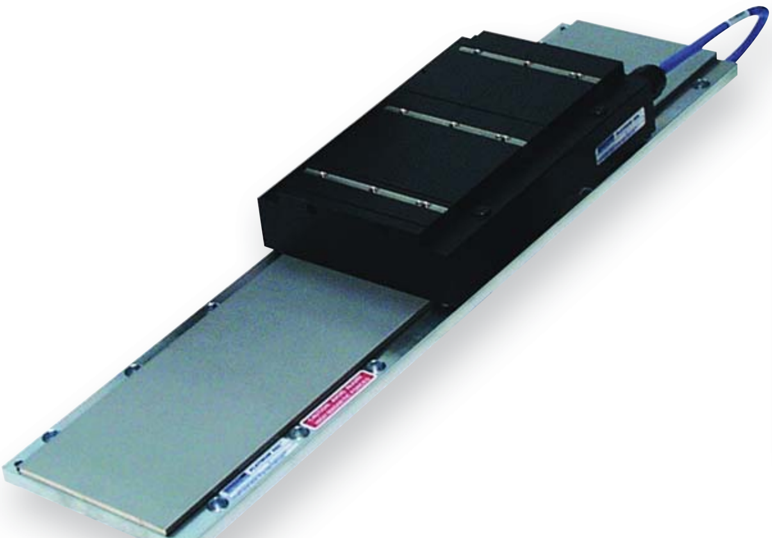
Many of the alternatives discussed here have implications for the servo drive. Many components impact accuracy issues. Designers will want to look at feedback-device families, the motor type (standard or direct drive), and the servoloop (support of dual loop). So, it is useful to start with a family of servo drives that gives flexibility with regard to the many available design options.

The servo drive

To improve system performance, one must also consider the drive. Flexibility is a key quality. A system that can accommodate several feedback and motor types will give more options for handling accuracy issues. Other areas of flexibility include accommodation of a wide range of servo algorithms, support of multiple communication buses (EtherCAT and CANopen, for example), and a large range of voltage and current models.

A key function of the servo drive is, of course, the execution of servo algorithms. There are multiple position/

Direct-drive motors such as Kollmorgen's DDL and DDR types eliminate the need for a transmission.



Authored by:
George Ellis
Chief Engineer, Servo Systems
Kollmorgen
Radford, Va.

Edited by **Leland Teschler**
leland.teschler@penton.com

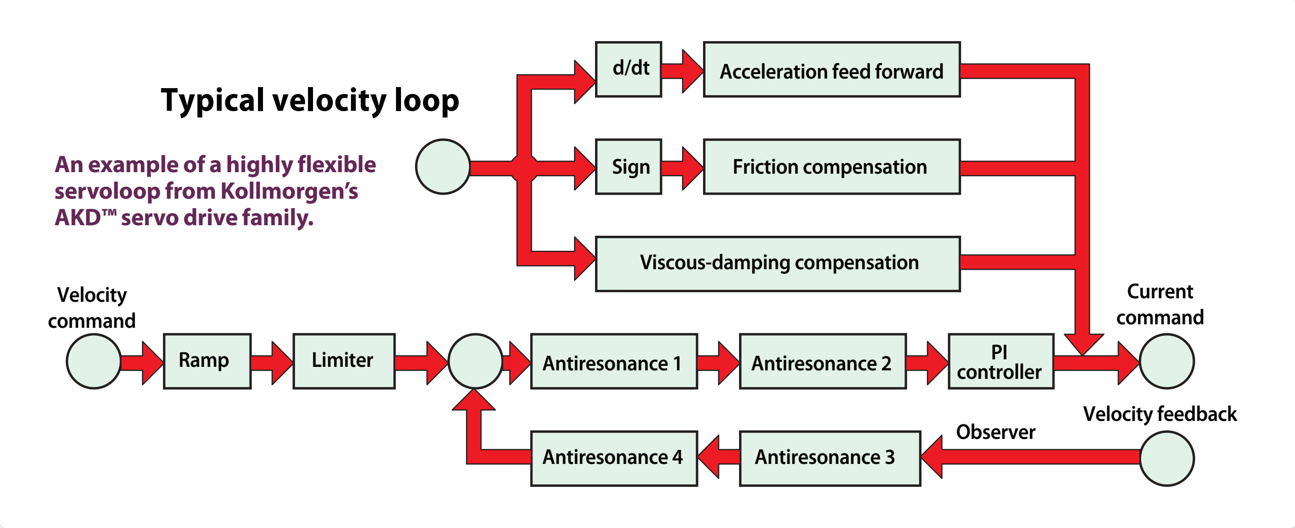
Key points:

- Three key measures — accuracy, response, and robust stability — characterize how servosystems perform.
- Not all autotuning algorithms are created equally. Many don't configure antiresonant filters or feed-forward gains.

Resources:

Kollmorgen, *www.kollmorgen.com*

Motioneering® application engine, *www.kollmorgen.com/motioneering*



velocity loop architectures used in modern servosystems, such as integrating position loops versus integrating velocity loops. In both cases, high servo gains generally contribute to faster response to both commands and disturbances. However, the placement of the integrator can favor different applications. For example, integrating position loops are often the choice as a way to minimize following error (the position error during a move command). On the other hand, integrating velocity loops often get the nod when the fastest response is needed.

Another family of functions that can help improve servosystems is feed forward. Feed-forward gains are added paths that speed response to command signals. Servoloops function by minimizing error: More position error generates a larger velocity command, which closes the error more rapidly. But loops take time to respond. By contrast, feed-forward is nearly instant and so forces the servo machine to respond more quickly.

Consider the effects of gravity on an overhung load such as an unbalanced vertical axis with a brake. Assume you enable the servoloops without feed-forward and release the brake. Initially the current command will be zero, so the load will fall a little. As the servo eventually reacts, its current will rise and the axis will go back to its initial position when the drive was enabled. However, observers will see a momentary drop. With "offset feed-forward," you tell the drive how much current is needed and the servoloops can be preset to that value before the brake releases. That way, when the brake does release, the load will barely move.

Current offset is just one type of feed-forward; other types include acceleration, velocity, viscous damping, and Coulomb friction feed-forward. All these functions share a key quality: The drive calculates the ideal response and adds auxiliary signals to the loop paths. This makes the output respond much more quickly to expected disturbances than would a servoloop without feed forward.

Of course, feed-forward gains are no substitute for high servo gains — all demanding applications require high gains to achieve rapid response. However, feed forward improves even the best-tuned servoloops, working together with the loops to give the most rapid response possible.

Compliance and stability

One area that limits performance in many servosystems is mechanical compliance. Mechanical compliance describes the flexibility between the motor and the load. Transmission components such as gearboxes and leadscrews are not nearly as rigid as they seem (at least not when viewed at the high frequencies where servos operate). In fact, they act much like a damped spring between the motor and the load. That spring makes it hard to realize high servo gains. This because, from the perspective of the motor, the load looks different at low frequency than at high frequency. A simple example demonstrates the problem.

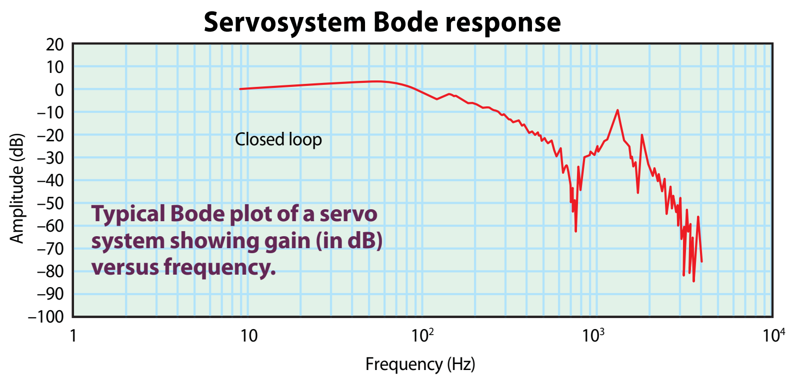
Imagine suspending an ordinary office stapler with a large rubber band. If you move your hand up and down slowly, the stapler follows your hand, and the inertial load your shoulder feels is your hand plus the stapler. But if you move your hand rapidly, the stapler will become almost stationary and the inertial load your shoulder feels will be, more or less, your hand. In effect, your hand disconnects from the stapler at high frequency.

There is an analogous situation with a servosystem when the motor (like your hand) tries to move the load (the stapler) through the transmission (the rubber band). At low frequencies, the total inertia is the motor plus the load; at high frequencies, the motor disconnects from the load and the inertia is, more or less, the motor.

This disconnection causes serious problems for servoloops. The standard PI (proportional-integral) or PID (proportional-integral-differential) servoloops are constructed to control a fixed inertial load. When the load varies with frequency, the loop gains often must be reduced just to ensure a stable response. When that happens, the loop performance falls, sometimes dramatically.

The initial way to address compliance is mechanical. There are two main alternatives: The first is to reduce compliance by using stiffer transmission components. Use servo-quality gearboxes, leadscrews, and couplings to minimize these problems.

The second alternative is to match the inertia of motor and load. That way, at the instant the load disconnects from the motor, the total inertia changes only by a factor of 2:1. (If the load is 10× the motor, the total inertia goes down by a factor of 11:1 at high frequency!)



Typical Bode plot of a servo system showing gain (in dB) versus frequency.

These solutions are good, but they have limitations. A transmission can be only so stiff before costs start getting out of hand. And boosting the motor size reduces acceleration and makes the system more costly (by use of a larger motor). At this point, designers turn to advanced antiresonant servo algorithms to improve performance further.

Antiresonant algorithms are velocity-loop filters configured to vary the response of the servoloops across the frequency band. Recall from the example of the stapler that the servoloop "sees" a total inertial that varies with frequency: large at low frequencies and small at high frequencies. The filters change the frequency response of the loop to compensate for that variation.

There are many alternatives for filter construction and placement in the loop. The simplest structure is to have a low-pass filter or two in the feedback path. Such filters are easy to use, but limited in the amount of improvement they can provide. More-advanced filters include notch filters (filters that attenuate a narrow band of frequency) and higher-order filters, which attenuate more rapidly with increasing frequency.

The most flexible filter is the bilinear-quadratic (biquad) filter, a filter that can be configured as a low pass, notch, or any number of other filter types. For example, Kollmorgen's AKD™ filter structure includes four biquad filters, two in the forward path and two in the feedback path. Such filter structures are highly flexible, allowing designers to deal with a wide range of resonance issues.

Bode plots

In addition to advanced algorithms, servodrive users should specify advanced servo tools. Biquad filters create a wide set of options, but it can be difficult to configure those filters. Many drives provide only the most basic diagnostic tools, often just a software oscilloscope that shows response in the time domain. However, resonance is more easily comprehended as a frequency domain problem so designers need tools that show the response of the system in the frequency domain.

The display of choice here is the Bode plot. For years designers have been able to create Bode plots using Dynamic Signal Analyzers or DSAs, instruments similar in size and complexity to oscilloscopes (and usually a lot more expensive!). Today, some servo drives such as Kollmorgen's AKD™ have DSAs built in so designers can easily view the frequency domain signals. These signals can display resonances, making the offending components easier to identify and ultimately correct.

Even with built-in DSAs, it can be difficult to find the optimal configuration for antiresonant filters. Another

IMPROVE ACCURACY	IMPROVE RESPONSE TIME	ACHIEVE OPTIMAL TUNING	IMPROVE RESONANCE PROBLEMS
Select a more-accurate feedback device	Increase servo gains	Select a drive with advanced tools such as a DSA to create Bode Plots	Make the machine stiffer, typically with better transmission components
Put a secondary feedback sensor on the load side of the transmission	Use advanced servo algorithms	Select a drive with a capable autotuning algorithm	Eliminate the transmission by using direct-drive motors
Use direct-drive motors	Use feed-forward algorithms		Use advanced antiresonant filters.

Machine designers who need to improve servo performance can evaluate alternatives as categorized into four general areas.

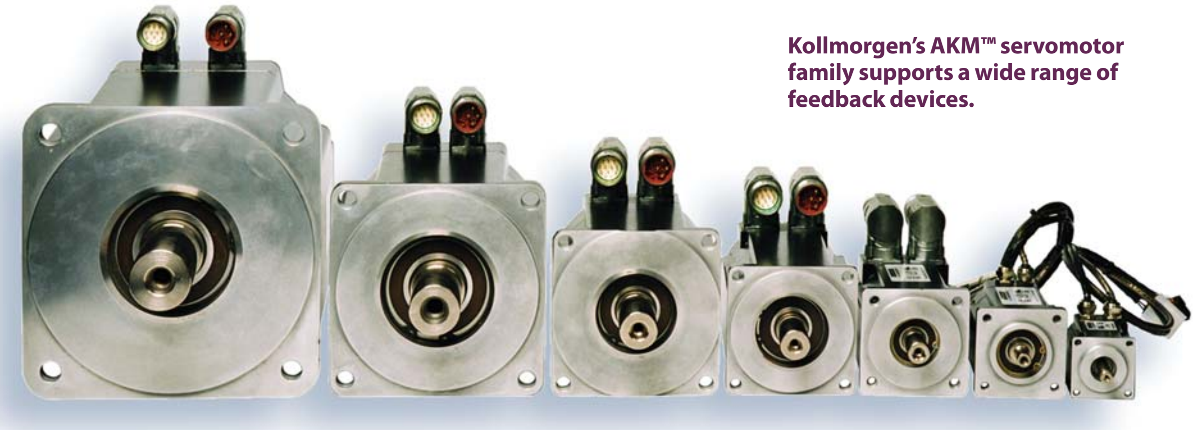
It can be easier to improve servo performance when drives support a wide range of feedback devices, servo algorithms, communication buses, and power ranges. Kollmorgen's AKD ™ servo devices are in this category.

tool that servomachine designers need is autotuning. Autotuning sets the servo gains automatically, providing fast, reliable servotuning even for complex mechanics.

However, not all autotuning algorithms are created equally. Many don't configure antiresonant filters or feed-forward gains. In fact, the simplest autotuning algorithms excite the load at low frequency and then set up the servoloops assuming the complete absence of compliance. That works well in a lab, where motors might be driving a steel wheel, but the results in real applications are usually disappointing.

When selecting a servo drive, select one with an autotuning algorithm that will cover all applications the drive might possibly see. If the algorithm is robust, it will save a lot of time and it will provide the high gains that give superior servo performance. For example, the AKD autotuning algorithm (patent pending) excites the machine across the full range of frequencies, so compliance can be thoroughly characterized. Then it configures a complete servoloop, including position and velocity-loop gains, multiple antiresonance filters, and many feed-forward gains.

All in all, there are a number of alternatives for making servos perform better. Start with flexible servo components allowing the use of different feedback devices, motor types, and servo algorithms. Configure servoloops to respond rapidly, even in the presence of mechanical compliance. And chose servo drives with advanced tools that promote a quick diagnosis of problems. **MD**



Kollmorgen's AKM™ servomotor family supports a wide range of feedback devices.

540-633-3545
www.kollmorgen.com
support@kollmorgen.com

KOLLMORGEN®

Because Motion Matters™