How to Design A Better Servo Control System

Lee Stephens, Danaher Motion

Servo control system engineers design systems that involve complex motion, such as this flat-panel display processing machine that incorporates a high-precision gantry system from Danaher Motion.

Servo control system engineers typically work designing new systems or redesigning existing systems for conveyors, pick and place machines, gantries, machine tools or other equipment. Of course, the new design task starts with a clean sheet of paper. Since this system did not exist before, all the specifications must be derived from calculations, simulations, or actual measurements on existing machinery. Engineers can measure feeds, speeds, loads and torques on similar equipment that operates without servo controls, or they can simulate them with a variety of software packages. On the other hand, servo control system engineers might have to redesign an existing system that typically comprises older analog controllers, sensors and drives.

Some might expect that designing a new system would be more difficult than replacing an old one, but often, this is not the case. Although the necessary loads, speeds and torques might be known, a newer digital controller behaves differently than the old analog system using brushed DC motors that it replaces. New control laws often enter the equation, and when the designer is not aware or does not anticipate these differences, the first system off the drawing board might not live up to expectations.

One major factor to consider in the new system is calculation time. A digital system works in three serial, quantifiable steps: measure, calculate and output. The controller requires specific time slices to run through these three functions. The calculation period might be so long as to let the system wander out of control. An analog system does not have this particular drawback to the same degree. By comparison, the analog system "calculates," measures and outputs almost simultaneously and continuously. Typically, the lag time is not as severe.

Both new and replacement systems follow the same basic laws of physics but different control laws, so the design approach and hardware shopping list could be very different for each system. For example, a new system design can be defined in two ways. The first is straightforward, where the controls engineer designs a system totally on his own from the ground up. He completely defines the system and orders the components needed to do the job. He alone is responsible for the outcome.

On the other hand, a new system might involve a client that has a resident engineer who helps define the system parameters and selects the components. The consulting motion controls expert may help design the client's new system after its resident engineer had already selected a few key components. The resident engineer may have determined loads, speeds and torques from actual measurements, calculations or simulations based on a few assumptions. He also may have purchased some major components such as motors and transmissions based on these determinations before hiring the consultant. The consultant's initial posture is to assume that the components that the resident engineer selected are perfectly suitable. Unfortunately, sometimes, this is not the case. The assumptions may have been made under static conditions when they should have been dynamic, particularly regarding the load. Then the consultant has no choice but to revise the model to include the proper parameters.

Strategy

Calculation lag time is especially troublesome when a control system contains multiple axes. In a three-axis pick-and-place system, for example, the x, y and z axes all must converge simultaneously on a particular point. If a lag appears in any one or more axes, the component part could be set in the wrong place. To avoid this, first determine the bandwidth of the system. Measure the load inertia, determine how fast it must move, and more importantly, how fast it needs to settle. Settling time really dictates the bandwidth. Bandwidth does not determine the speed, but how quickly and precisely the load stops or follows a contour.

The bandwidth is usually defined in terms of its −3 dB point and the 45° phase shift. Don't prefer one parameter over the other; exceeding the −3 dB point and the 45° phase shift indicates that the system is out of control. For example, if the system is at −3 dB but it has a 60° phase shift, it was significantly out of control long before it hit the −3 dB point.

In digital systems, other functions affect the phase angle, which sometimes surprises the customer. It concerns current-loop bandwidth. It is calculated digitally, and the calculation delays become apparent. The delay is worse than a phase shift, but it is essentially the same thing. Phase is time in the frequency domain. The digital system may not have optimized control algorithms to calculate current, velocity or position. Then the digital system may have more of a calculation delay than the system can tolerate. It did not achieve the intended bandwidth.

Modeling

Some of the design work is carried out by modeling with a variety of software packages. Systems may be modeled in a digital format to determine not only the bandwidth, but also the position accuracy. The model can become as detailed as necessary.

Widely used software packages include *DisSim*, *Mathcad*, and *Motioneering*, which is available from Danaher. A *Motioneering* model for a typical PID controller lets designers examine the system behavior with numerous gains and other parameters. It can show a plot of this behavior with certain perturbations. *VisSim* also is a widely used simulation software package. A limited trial version may be downloaded free of charge from *www.vissim.com*. The trial version can run and modify a model, but it cannot save the model. However, the full purchased package performs the complete job. *Motioneering* is free and determines how much current and power the motor needs to function properly. *Mathcad* is another modeler that many designers use.

When modeling, it is sometimes hard to decide when to stop. When designers gain sufficient experience, however, they can recognize when some of the parameters are not relevant enough to consider. In the beginning, try everything on the list. Then narrow it down to the few parameters needed to adequately and sufficiently model the system. Any adjustments after that are usually minor. Stop when further detailing does not make the model any better or does not gain any more advantage in the design.

Often, designers return to the model

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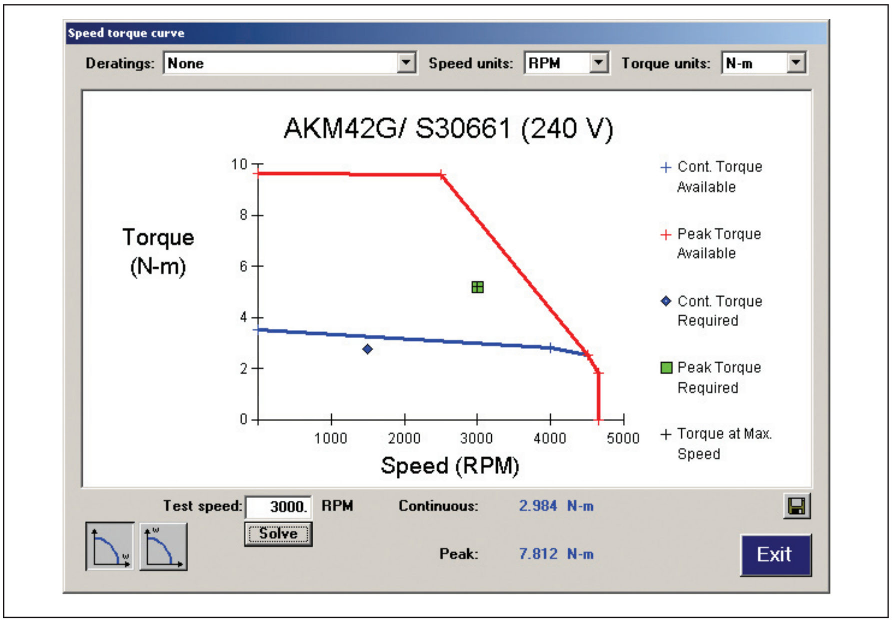


Engineers can use software such as *Motioneering* from Danaher Motion to model their systems before building them.

after the system did not meet specifications, and they find errors. They go through the system and might find that they should have considered something else that was more important. Always try to validate the model. It is only as good as the information that goes into it. Some information is difficult to determine mathematically and has to be done empirically. However, the empirical information determined for the model may not be sufficient, so use multiple formats, including the frequency domain and the time domain. *VisSim* and *Mathcad*, for example, work well together for this, so take advantage of them.

Validation

After the model is completed, the hardware may not yet be available to work with. The customer may have the breadboard and prove that the supplier's products will work in his system. However, the consultant may not be in control of how close the breadboard represents the real system. He may use the model as supplied, or he may revise it and find changes in pulley ratios, motors, inertias or miscalculated inertias. However, assume the physical breadboard is sufficient to model and validate the system. In the next step, the customer now implements the alpha or beta stage of the project and buys the needed components. When the system does not meet expectations, sometimes the problem is a miscalculation; the system was expected to operate under certain circumstances, but maybe it could not. The model should have shown how much headroom there was and how close it was. If not, then it may be necessary to construct a Bode plot or run an FFT (fast Fourier transform) to find out why the system is vibrating, resonating, or not rejecting the disturbance. The ability of a control system to reject disturbances is a figure of merit that goes beyond a number; it is intuitive. It is through feedback that the disturbances will be rejected. The proper feedback loop will let the load reach the intended position. This might involve velocity, position or torque feedback. The nature of the feedback loop depends on the function that is specifically needed, such as torque or current for machining operations.

Feedback

The feedback system complexity varies with the application. It can be as simple as an incremental encoder or a resolver, and there are different reasons for using one or the other. A resolver is extremely robust and can tolerate harsh environments well. It can be a sine/cosine encoder, which can handle very high bandwidth, but typically, it does not survive well in a high-vibration, high temperature environment.

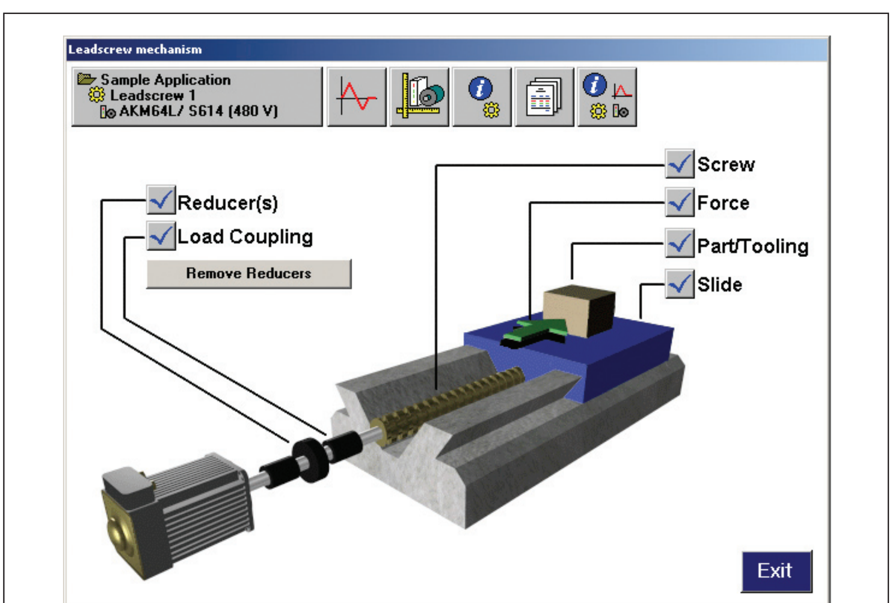
Some systems are more complex when they need a secondary feedback device. For instance, a system may require a feedback device mounted directly on the motor and another closer to the load. The feedback device on the motor could be used for velocity control, but the feedback device on the load would be used for final position. It doesn't sound too difficult, but as the feedback device moves farther from the transmission device (which is the motor here), more items will be enclosed in the loop. For instance, when a resonance appears at a certain frequency that is outside the intended control bandwidth, having the feedback device outside of the load is certainly going to help move the load to its final position. However, this system is extremely difficult to tune. Tuning this system means getting the position system up to the desired performance level. Therefore, when a very high-bandwidth position loop is needed, a secondary encoder is typically placed at the end of the position loop.

Redesign

During tuning, sometimes the controls engineer will find that rather large modifications must be made to the system to gain the intended control. He may even have to change his entire theory regarding the method needed to tune the system.

The simplest control methods, either PID (proportional, integral, derivative) or PIV (proportional, integral, velocity), usually operate in a great number of systems. For example, a standard PID control system is relatively easy to tune. It can be used for either a new system or an old one. Here, the velocity is a derivative of position and used for damping. The proportional term is a gain factor.

Also, a math calculator using a pole/zero function or a post filtering biquad filter method can help in the design. But either has certain advantages and disadvantages. The PID is probably the simplest to understand and implement using classical control laws. During testing or any time the system is in production, however, some control laws may need changing. After some use, however, the first single PID system may not appear to work sufficiently well. It may require



Motioneering helps determine how much current and power a motor needs to function properly.

two PID systems, a biquad system, or additional low-pass or high-pass filters.

Stiffness

System stiffness, or a lack of it, seems to be a major, chronic problem. For instance, resonance problems indicate that a system is not stiff enough. Moreover, backlash in a system is another serious problem. Here, the customer may have a linear motion control system that specifies a rack and pinion transmission on a precision axis. However, such a single-format gearing system produces troublesome backlash. Even anti-backlash gears cannot solve the problem; often they still have enough backlash to create instability. They typically contain two gears in parallel. One is spring-loaded against the other, and the teeth are clamped from two different directions. That arrangement does not guarantee zero backlash, only that the backlash is taken up by another mechanism. They have a spring rate to contend with, which is a dilemma when trying to control a frequency in the domain of the spring rate. It is a common problem, usually found in a system designed by someone lacking controls experience.

To overcome these problems, conduct Bode plots and LaPlace transforms in the frequency domain. Compare the Bode plot performance with the LaPlace transforms and tune the system based on that information. Observe the frequencies, disturbances and amplitudes, then determine the best method of attack to eliminate the disturbances, or insert compensation to reject it. In addition, stiffen the system to eliminate resonances, and raise the frequencies above the frequency of disturbance. Also, sometimes the system may be damped, but this could also affect the compliance. High frequency damping usually does not add compliance, but at low frequencies, damping certainly cannot be added because it adds compliance that exacerbates the disturbance itself. Try using acceleration feedback, a Lowenburger observer—a relatively complex algorithm—or select a suitable filter.

For more information:
Danaher Motion
1500 Mittel Blvd.
Wood Dale, IL 60191
Phone: (540) 633-3400
Fax: (540) 639-4162
Internet: *www.danahermotion.com*

Motion Engineering Software

The following resources provide software that may be valuable in developing motion control systems.

Mathcad
PTC
140 Kendrick St.
Needham, MA 02494
Phone: (781) 370-5000
Fax: (781) 370-6000
Internet: *www.ptc.com*

Motioneering
Danaher Motion
1500 Mittel Blvd.
Wood Dale, IL 60191
Phone: (540) 633-3400
Fax: (540) 639-4162
Internet: *www.danahermotion.com*

VisSim
Visual Solutions Inc.
487 Groton Rd.
Westford, MA 01886
Phone: (978) 392-0100
Fax: (978) 692-3102
E-mail: *info@vissol.com*
Internet: *www.vissim.com*

Lee Stephens *is a systems engineer with Danaher Motion in Wood Dale, IL.*