The Lead to Linear Speed

Can better sensing and control overcome torsional issues?

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Question from a machine builder: “We’ve used leadscrews in our linear motion applications for years because they give us high stiffness, very acceptable backlash, and simplicity. As performance requirements increase, we’re going to have problems with the leadscrews not accelerating quickly enough to high speeds. It looks like we have some torsional issues as well. Can we overcome this with better sensing and control? Is it time to look to an electronic answer?”

Answer: As with most technical questions, I typically like to ask about 10 more clarifying questions before I make a recommendation.

For starters, it would help to understand what acceleration you are trying to obtain. Under ideal conditions, a lead screw can accelerate at 20 m/s2. If you require accelerations that are significantly larger, you will likely need to look at alternate drive train technologies, such as a linear motor, which is capable of 50 m/s2 or greater. If an acceleration of 20 m/s2 would satisfy your application's requirements, please read on to see what might be limiting your current system's performance.

There are several factors that will limit the acceleration that any screw is capable of. The most common limitation is the critical speed of the screw, also known as "whip." Critical speed is defined as the eccentric motion of the drive screw that occurs when the rotational velocity (rps) of a screw is exceeded. If the screw's critical speed is too low, then the ability to accelerate will also be limited.

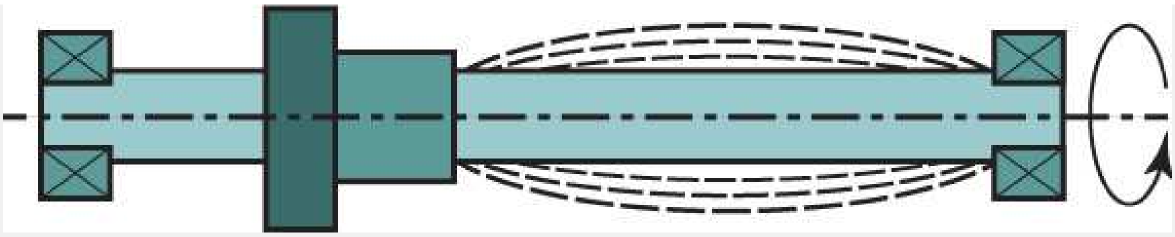
Fundamentally, a screw's critical speed is a function of two variables: the diameter and the length of the screw.

$$N = (10.6 \times 10^6 \times d)/L^2$$

where N is the critical speed, d is the screw diameter, and L is the length between bearing supports. Note that the formula assumes both ends of the screw are rigidly fixed.

The critical speed and the screw diameter have a direct relationship, so an increase in diameter will increase the critical speed. However, the critical speed and the screw length have an inverse relationship, so the longer the screw is, the lower the critical speed will be (Figure 1). Knowing this, the acceleration capability can be improved by either increasing the screw diameter, shortening the screw length, or some combination of both.

Another way to avoid critical speed issues, while increasing acceleration capability, is to change the lead of the screw you are using. The screw lead is the axial advance that is realized from one complete turn (360°) of the screw. For example, a 5 mm lead screw will have a linear translation of 5 mm per screw rotation. Increasing the lead of the screw will increase the speed and acceleration attainable without increasing the critical speed. Please note that by increasing the lead of the screw, you will sacrifice some mechanical advantage, and the torque required from the motor will increase as well.



Size for Speed

Figure 1: An increase in screw diameter increases critical speed, but an increase in screw length decreases critical speed.

If critical speed is not the issue, then there could be an issue with the amount of torque available. If you consider the components that make up the total required thrust force (acceleration force, force of gravity, and force of friction), the force required to accelerate your load is the largest contributor. It is possible that the motor you are using does not have enough torque to reach the accelerations that you are trying to achieve. There are relatively simple calculations that can be done to see what your maximum required torque is. Once that is known, you can make sure that your motor is properly sized to reach your desired accelerations.

Your question also refers to a solution with “better sensing and control.” You don't mention what your current setup is, but if you are using a stepper motor that is an open-loop system, switching to a closed-loop servo motor solution, which certainly could be considered to have better sensing and control capabilities, could help in a roundabout way. As I mentioned, acceleration is all about torque. When you look at the continuous torque of a similarly sized stepper motor and servo motor (NEMA 23, 3 stack, for example), you will find that their torque densities are relatively close. The servo motor, however, has a peak torque region that a typical stepper motor will not have. This peak torque region allows the motor to put out some multiple of the continuous torque (our motors are rated at 3x) for a specified amount of time (our motors are rated for roughly 10–30 s based on winding and frame size). The ability to increase the torque output for a short period of time allows a smaller servo motor to solve applications where the acceleration torque requirements exceed that of the continuous torque rating on the stepper. With all of that said, though, increasing the size of the stepper motor — to, say, a NEMA 34 — could give you a continuous torque rating that is large enough to satisfy the application's acceleration torque requirements.

If none of the above suggestions yields the acceleration performance you require, I would recommend that you start looking at alternate drive trains to meet your acceleration requirement. If high stiffness, low backlash and high accelerations are the goal, then we will likely be looking at a linear motor to meet your application's requirements. The linear motor does not have the mechanical limitations that screw solutions do. Additionally, if the linear motor solution you go with is a servo, you will gain the sensing and control functionality associated with a closed-loop system. The downside of this path is that a servo-driven linear motor system is typically more expensive than a rotary motor screw-driven solution.

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