Applying step motors successfully

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Day 1
Torque and inertia

Topics of discussion:
✔ Torque
✔ Inertia

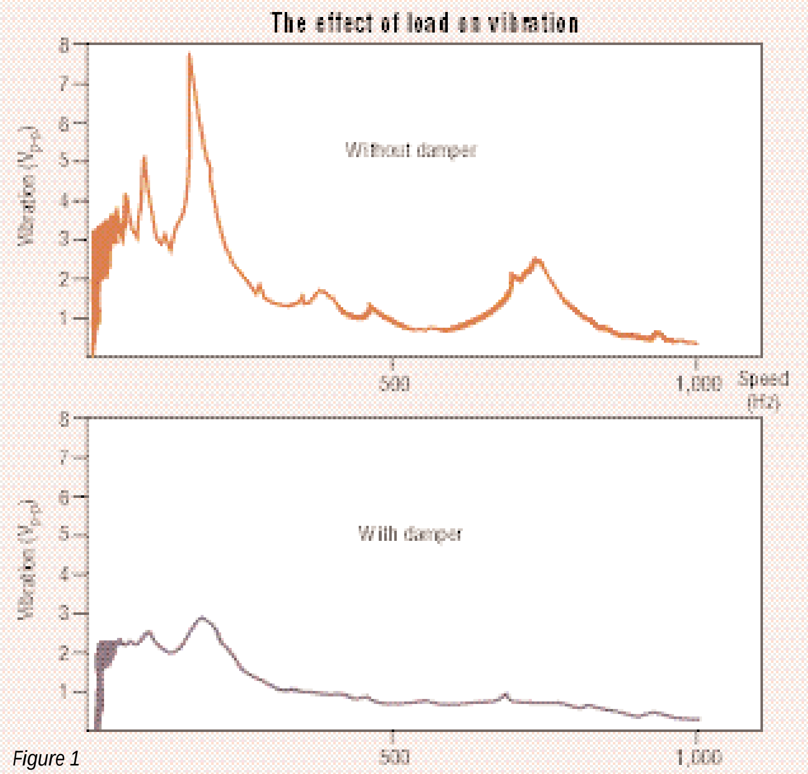


Figure 1

The addition of a damper, simulating a load, reduces shaft vibration in a hybrid (toothed rotor) stepper. Vibration peaks correspond to rotor teeth overshooting opposing stator teeth and settling back to position.

Step motors are a natural choice when design specs call for low-cost automation with accurate, open-loop control. But finding the right stepper for a given application can be a challenge. There's a lot to consider — step angle, rotor inertia, torque, and speed — and none of it makes sense outside the context of the application.

With step motors, the motor and load *are* the system and must be optimized simultaneously. In some cases, one spec may need to be sacrificed for another for the greater good. For example, if high torque is the priority, then it may be necessary to trade off step angle and resolution. The choice comes down to how the load and motor work together. In this series, we will consider key motor parameters as well as common loads.

Torque

Torque, as it relates to motors, is defined as

$$T = F \times R \qquad (1)$$

where F is the force applied over a distance R.

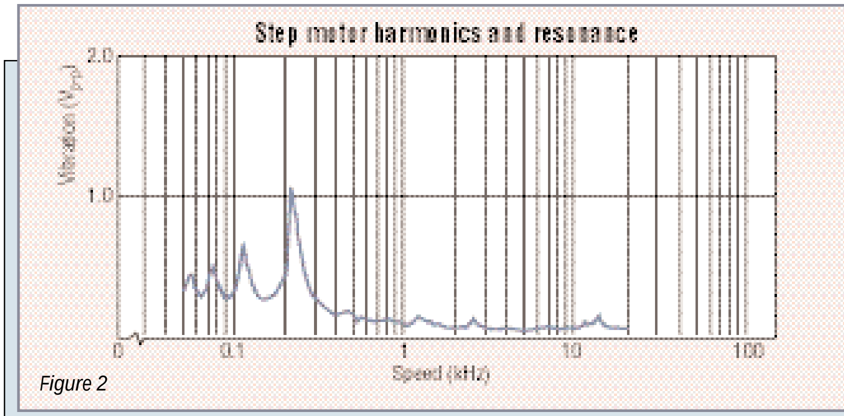
Required torque — to achieve a specific motion — is defined in terms of **acceleration torque** and **constant torque** (sometimes called *frictional torque*). Although it may take very little torque to overcome frictional losses in, say a ball screw, it may take considerable torque to get the screw up to speed when driving a heavy load. This potentially large component, known as acceleration torque, depends primarily on system inertia.

Now step motors generate fairly constant torque up to the knee of their torque-speed curves. Established by motor manufacturers, these curves are usually created with the motor driving a light load (such as a damper) because steppers need to be loaded to run properly. *Figure 1* — responses for a hybrid (toothed rotor) stepper — shows why a step motor needs to be loaded.

Having a load is not enough, however. Step motors must be carefully sized for the system in which they are intended. **Required torque should be somewhere between 30 to 70% of the motor's rated torque.** This is a good rule-of-thumb to make sure the motor is neither too lightly nor too heavily loaded.

If the intended load is very heavy compared to the motor's output torque, the motor will miss steps and will not be able to properly position the load. Even if a system can make do with an undersized motor, it probably won't perform very well at high speeds.

Ironically, lightly loaded systems often behave similarly. If a system requiring only 2 oz-in. of torque gets 100 oz-in. from the motor, the excess torque has to go somewhere. As in the case of an un-



Step motor vibrations peak at a pulse-input frequency of around 200 Hz. Here, loading is a particularly important issue. Further down the spectrum, audible frequency harmonics appear and can be quite noisy if not damped.

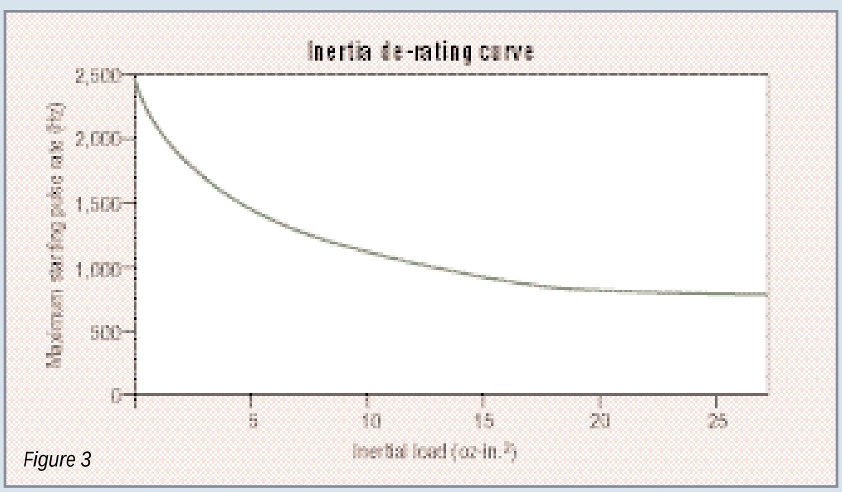
loaded motor, it will go into vibration. This can cause all sorts of problems. In fluid dispensing applications, it might cause spills. In microscope positioning systems, the problem might be blurred vision or missing the target altogether.

Inertia

Inertia is a property that relates to size, mass, and the tendency of an object — in motion or at rest — to remain in its present state. Newton described it well in his first law: An object in motion tends to stay in motion, and an object at rest tends to stay at rest unless acted on by an outside force. In the case of a stepper motor, the force is usually friction.

Consider a step motor trying to start a load. Not only must the motor contend with load inertia, it also has to get *its own* inertia going. In general **it is recommended that load inertia be no more than seven to ten times that of the rotor** although inertia mismatches much greater can be overcome by correct timing of input pulse profiles. For high-performance moves (usually 1 sec duration or less) the ratio should be somewhere between 3:1 and 1:1. Gearing the motor can curtail inertia mismatches, reducing reflected inertia (back to the motor) by the square of the gear ratio.

Rotor inertia can have a major effect on how well a stepper-based system operates. For example, the motor may have sufficient torque to move the load, but if there is too great an inertia mismatch, it may not be able to start and stop the load accurately. The stepper controller may have to be programmed with a lengthy acceleration ramp profile in order to get the load moving without inducing lost synchronism. In addition, the deceleration profile may also have to be quite long to stop accurately without the load's inertia "back-driving" the motor and missing steps.



The maximum pulse rate for starting a step motor depends on the load. The higher the inertia, the lower the rate. If the pulse rate is too high, the motor will likely miss steps.

The maximum pulse rate for starting a step motor depends on the load. As more inertia is introduced in the system, the starting pulse rate must decrease to ensure that the motor will not miss steps starting and stopping. This can be seen graphically for a typical stepper in *Figure 3* and in the following equation

$$f = f_s/(1 + J_l/J_o)^{0.5} \qquad (2)$$

where f is the calculated loaded starting pulse rate, f_s is the unloaded motor starting pulse rate, J_l is the load inertia, and J_o is the rotor inertia. For example, if we have an inertia mismatch between the rotor and load of 3:1, then our new starting pulse rate will be cut in half.

Step motors, as noted, actually must generate two torques — frictional torque and acceleration torque. Acceleration torque involves overcoming system inertia. To neglect this component is a common mistake that invariably leads to an undersized motor and unacceptable performance.

Acceleration torque is calculated by multiplying system inertia by the acceleration rate (usually in radians/sec^2)

$$T_a = J \times a \qquad (3)$$

where T_a is the acceleration torque, J is system inertia, and a is the rate of acceleration. ●

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