Actuator Characterization

Covers models T-NAXX, T-LAXX, T-LSXX, T-MMXX, and T-NMXX

INTRODUCTION

Zaber's T-Series of computer-controlled positioning devices use stepper motors to achieve open loop position control. These devices turn by a constant angle, called a step, for every electrical impulse sent to them. This allows a system to be built without feedback, reducing total system cost. It is also possible to rotate the motor by an angle less than a step by using a technique called microstepping. This consists of using an analog current in the motor coil in place of full current switching. Stepper motor technology is well described in many books and websites.

However, being incremental (as opposed to absolute) in nature, the stepper motor must initially be zeroed by going to a home sensor. Also, if the torque required becomes higher than the maximum torque (or stall load) of the motor, a stall condition will occur and the motor will stop turning. To avoid this situation, try lowering the speed, the acceleration, or the load. Stalling does not damage the motor. However, because there is no position feedback, the actual position of the device will become different from the position indicated by the controller.

The Zaber devices listed below in Table 1 use a direct drive system for a simplified mechanical design with no coupling, gear, belt, or other components. Some critical characteristics of the stepper motors used in Zaber's devices are given in the following table. These devices use a setting of 64 microsteps in every step by default (i.e., 1 microstep = 1/64 of a full step). They are capable of even higher resolution, but for simplicity's sake, the data below has been generated assuming the device is set to 64 microsteps/step.

PRODUCT	MOTOR SPECS			LEAD-SCREW	
	Steps per revolution	Microsteps per revolution	Degrees per microstep	Pitch in μm per revolution	Resolution per microstep
T-NA	200	12800	0.028125	609.6	0.047625 μm
T-LA, T-LS	48	3072	0.1171875	304.8	0.09921875 μm
T-MM2	48	3072	0.1171875	304.8	0.000086°
T-NM*	200	12800	0.028125	N/A	0.028125°

TBL 1: MOTOR AND LEAD-SCREW PROPERTIES OF ZABER T-SERIES DEVICES

*T-NM products are motors only with built-in controllers. They do not contain a lead-screw.

RESOLUTION

The resolution (also called addressability or microstep size) is the distance equivalent to the smallest incremental move the device can be instructed to make. In other words, it is the linear or rotational displacement corresponding to a single microstep of movement. As seen in Table 1, the resolution for T-LA and T-LS devices is 0.09921875 μm (or approximately 0.1 μm). For T-NA devices, the resolution is 0.047625 μm. For T-NM devices, the resolution is 0.028125° of rotation. The resolution of the T-MM2 mirror mount is 0.000086° of tilt for either axis.

REPEATABILITY

The repeatability is the maximum deviation in the position of the device when attempting to return to a position after moving to a different position. Figure 1 is an example showing how this specification is determined. The histogram shows the number of times the actuator stops at a given position. The two peaks correspond to each direction of approach. Within each peak there is a Gaussian distribution with a full width at 1/e2 of about 0.3 μm. This is a typical repeatability for T-LA actuators. The distance between the two peaks is 2.2 μm. This is a typical backlash.

ACCURACY

The accuracy is the maximum deviation of the actual position of the device from the requested position over the full range of motion. Figure 2 and 3 are examples showing how this specification is determined. The cyclic error of +/-3 μm peak deviation with a period of one motor rotation (48 steps or 304.8 μm) is typical of lead-screw systems. The big jumps are due to the poor resolution of the gauge (1 μm). A non-linearity of about +/-2.5 μm maximum deviation can be seen. To obtain the actual accuracy, you must add the cyclic error on top of this slowly changing error. This pushes

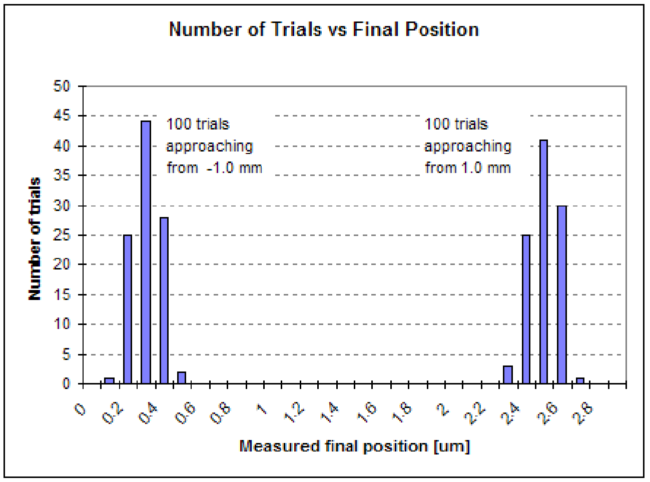


FIG 1: NUMBER OF TRIALS V.S. FINAL POSITION

Test procedure: A T-LA28A actuator is moved 1 mm from a given position and then back to that same position. This is repeated 100 times and the true position is measured each time (the accuracy of measurement is +/-0.1 μm). The test is repeated with the actuator moving 1 mm in the other direction before attempting to return to the same position. All tests are made with the actuator mounted to a TSB28 translation stage.

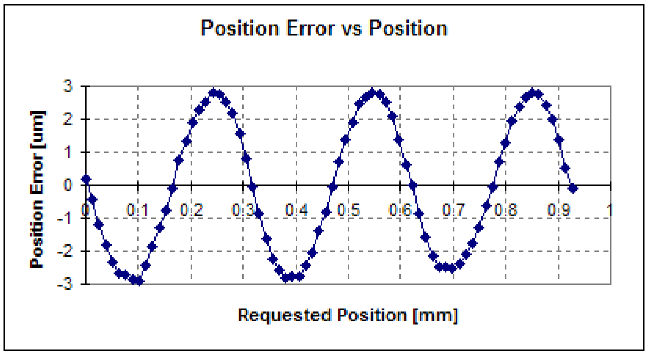


FIG 2: POSITION ERROR V.S. POSITION

Test procedure: A T-LA28A actuator is moved in one direction in one step (6.35 μm) increments. The position error (the measured position minus the requested position) is plotted as a function of the requested position.

the maximum deviation to 2.5 μm (non-linearity) + 3 μm (cyclic) = 5.5 μm maximum deviation from 0 error. Therefore the accuracy of the tested actuator is +/-5.5 μm. Devices with greater travel will generally have poorer accuracy over their full range.

STABILITY

A specification of any positioning device is its ability to stay at the same place for an extended period of time. The worst problems for stability are internal and external temperature changes. These temperature changes produce thermal expansion and generate motion of the payload. Although powering off the motor between moves greatly reduces the thermal load on the actuator, prolonged motion at high duty cycles can generate enough heat to cause trouble. All motorized actuators, even those using DC servo motors, face this problem.

Figure 4 shows a time constant of about 20 to 30 minutes and a maximum amplitude of 37 μm. The position does not return to zero after cooling. This is likely due to creep of the lead-screw in the rotor thread and/or creep of the bearing holding the rotor. The temperature rise of the motor at full current is 75°C. Note that this is a worst-case scenario with full current applied continuously. During normal operation, temperature changes are much lower.

If the long-term stability of the unit is a concern (it may not be for many applications, especially closed loop systems), the unit should be turned on at least 20 minutes before using it and small motions with low duty cycles (<5%) should be used.

Temperature effects should be kept in mind if larger movements or high duty cycles are required. If you repeat the same readings several times during an experiment and notice an increasing or decreasing trend in readings which you expect to be constant, consider the possibility of thermal effects.

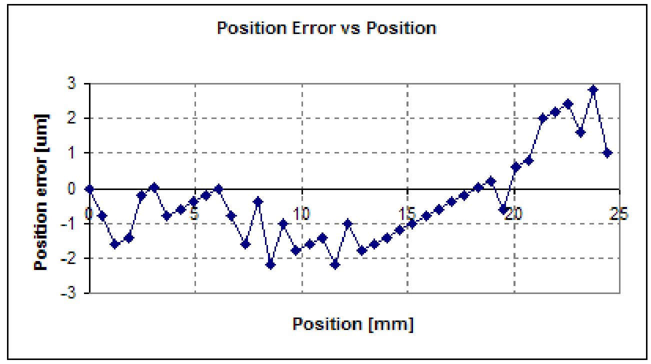


FIG 3: POSITION ERROR V.S. POSITION

Test procedure: The T-LA28A actuator is moved from 0 mm to 25 mm in increments of two revolutions of the stepper motor (96 steps or 0.61 mm) to avoid measuring the cyclic error shown above. The position is measured with a digital dial gauge with a resolution of 1 μm.

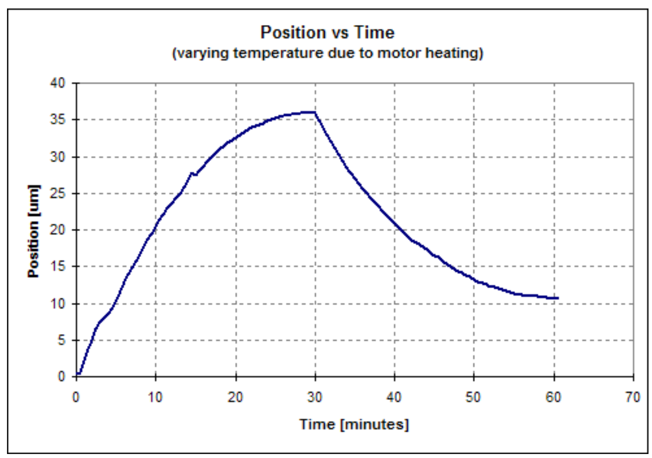


FIG 4: POSITION V.S. TIME

Test procedure: The T-LA28A electronics are switched on but the motor is turned off. The set-up is left alone until the actuator, translation stage, and Mitutoyo Mini-Checker attain thermal equilibrium. Then (at t = 0 in the chart above) the maximum rated current is applied to the motor winding. This does not turn the motor but dissipates 3.4 watts of power inside the motor, causing its temperature to rise. The Mitutoyo is then read every 30 s until the position stabilizes. Then (at t = 30 in the chart above) the current to the motor is switched off and the gauge is read every 30 s until the position stabilizes again.

STICKTION

Because of friction, the device may not move at all when requested to move by one microstep. Requesting it to move another microstep may still yield no results. After a certain number of one microstep requests, the force will exceed the static friction and the motor will jump by the accumulated number of microsteps and then stick again. This phenomenon is called sticktion. It is very dependent on the load and on the state of the lead-screw.

Most positioning devices face this problem to some degree. After taking up the backlash, T-Series devices in good condition with a small load will move on each microstep. At higher loads, which increase the lead-screw friction, they may jump every micron or so.

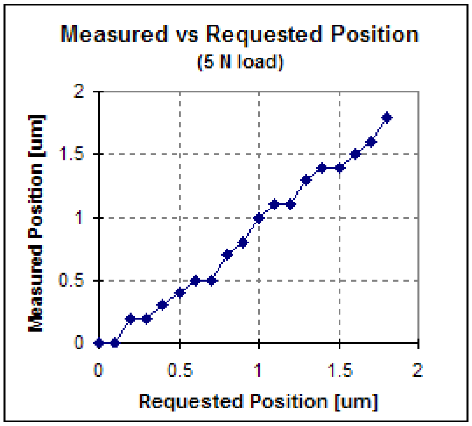
Note that since the resolution of the gauge is 0.1 μm, the same as the motion being measured, some of the apparent jumps are simply due to rounding error.

BACKLASH

As discussed in the repeatability section, backlash is the deviation of the final position that results from reversing the direction of approach. However, for small movements, the backlash is more complicated than that. In general the actual position of the device is not uniquely determined by the requested position but depends on the exact trajectory used to get there. For small motions involving a change of direction the repeatability may be said to go to the backlash level.

ANTI-STICKTION AND ANTI-BACKLASH FEATURES

If you want to move your device by small amounts, for example to align an optical fibre on a diode laser, sticktion and backlash can become very annoying. Zaber T-Series devices have built-in anti-backlash



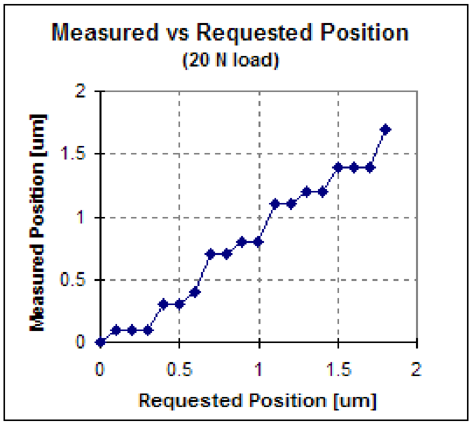


FIG 5: MEASURED V.S. REQUESTED POSITION

Test procedure: After taking up the backlash, a T-LA28A actuator is requested to move in one microstep (0.1 μm) increments. The position is measured with an accuracy of +/-0.1 μm. The test is done first with a small load of 5 N and then repeated with a load of 20 N.

and anti-sticktion routines that can be enabled to help solve this problem. They are disabled by default. The anti-backlash mode does not affect motion in the positive direction (increasing absolute position). For negative motion, however, the device will overshoot the desired position by roughly 600 microsteps and return, approaching the requested position from below. The anti-sticktion mode does not affect movements larger than 600 microsteps. For requested movements smaller than 600 microsteps, the device will first position itself 600 microsteps below the requested position and then approach the requested position as usual. Care must be taken in certain situations. For example, when aligning an optical fibre to a laser at a distance less than 600 microsteps, the fibre may collide with the laser if the direction of travel of the positioning system is not chosen wisely.

Zaber Technologies is a manufacturer of high-precision positioning devices and systems. In the late 1990's, we introduced the world's first precision linear actuator with all control and drive electronics integrated into one compact package. Since then, our product line has grown to include a wide range of motion devices, most with optional built-in controllers and drivers. For more information, please visit: www.zaber.com.

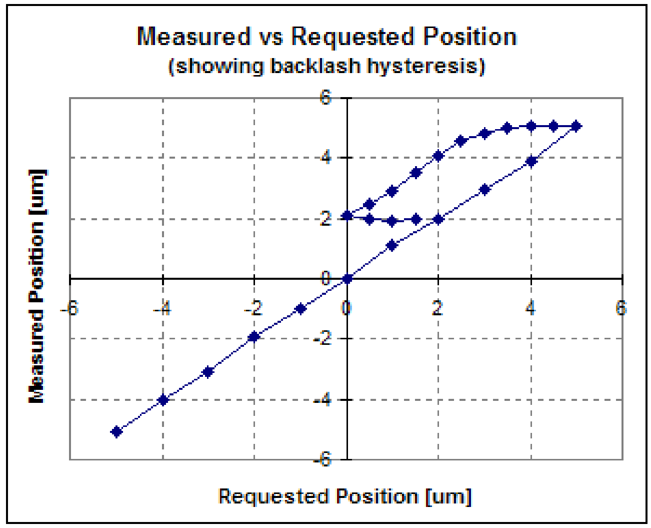


FIG 6: MEASURED V.S. REQUESTED POSITION (SHOWING BACKLASH HYSTERESIS)

Test procedure: Approaching from a large negative position, a T-LA28A actuator is requested to stop at 5 μm. It is then requested to move back to 0 μm and finally forward to 1.5 μm. The actual position is measured and plotted as a function of the requested position.