

NTS NanoDirect (NTS10, NTS25, NTS100)

Nanopositioning Piezoelectric Linear Stages with Long Travel Distance

Technical Note

How can the NTS NanoDirect provide nanometer resolution and long travel range simultaneously?

All current commercial piezoelectric translators (PZTs) used for nanopositioning suffer from one very important disadvantage - they have a very limited travel range (typically from 5 μm to 200 μm). By comparison, stages that use alternative motorized systems, such as DC or stepper motors, offer extended travel ranges (eg 10 -100 mm), but provide relatively low resolution (typically 0.1 μm or worse). This makes them inadequate for nanopositioning applications. Another significant limitation of the current PZT nanopositioning systems is the relatively large drift rates (between 1000 and 2000 nm/hour @ 20°C), which clearly undermines positioning repeatability and accuracy. Usually the drift arises from inaccuracies in the applied voltage during nanopositioning.

NTS NanoDirect is a hybrid nanopositioning system, which combines both nanometer-sized incremental steps and extended travel range – from 10 mm to 100 mm. The design principle is based on converting the rotational movement of a unique and highly precise piezoelectric rotary motor into linear motion using a precision electro-mechanical design under Digital Signal Processor (DSP) control. The design also eliminates the “stick-slip” effect, which typically limits nanometer resolution in conventional mechanical positioners.



NTS NanoDirect Stage



NTS 3-channel DSP Controller

“stick-slip” effect, which typically limits nanometer resolution in conventional mechanical positioners.

Characteristics of the rotary piezoelectric motor

Angular resolution

One of the most critical factors determining the linear resolution of the NTS NanoDirect system is the angular resolution of the piezoelectric rotary motor. The minimum angular increment/step of 1 arc sec was measured using a laser autocollimator as shown in Figure 1. A mirror is attached to a table that is firmly mounted to the shaft of the motor. The test entails measuring the change in the angle of reflection (when the motor is rotated at its minimum angular increment) of a collimated light beam, originating from the autocollimator and reflected back from the mirror. The method enables angular movement to be resolved to better than 0.5 arc sec.

Torque

Another critical parameter of the rotary piezoelectric motor is its extremely high initial torque (0.2 Nm), compared to the torque of a comparable stepper motor (e.g. 0.01 to 0.05 Nm). This high torque allows the use of a high-tension spring load, which ensures continuous contact between the lead screw and the moving stage platform irrespective of the direction of movement. This guarantees high resolution of NTS NanoDirect and by minimizing backlash.

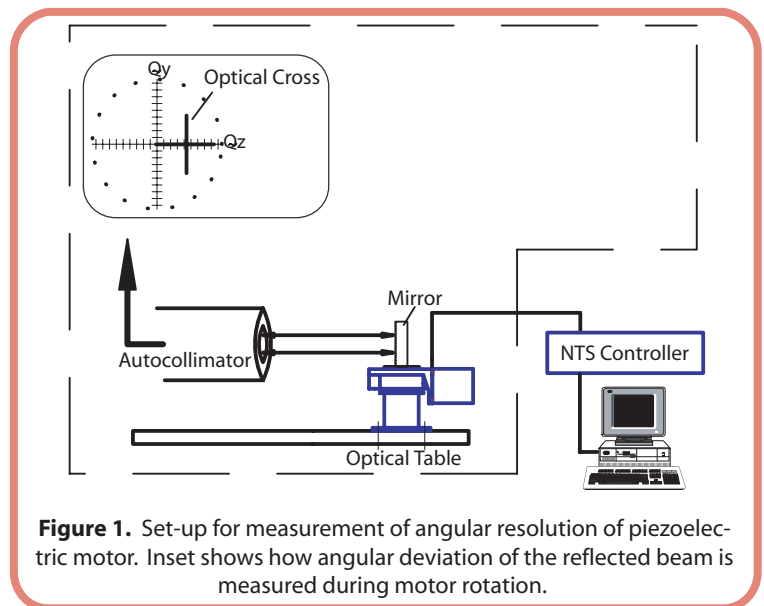


Figure 1. Set-up for measurement of angular resolution of piezoelectric motor. Inset shows how angular deviation of the reflected beam is measured during motor rotation.

Characteristics of the translational stage

The mechanical characteristics of the translation stage have been carefully designed to provide the highest achievable resolution. A summary of these design characteristics is given below:

Lead screw assembly

The lead screw assembly of the NTS NanoDirect has been precision engineered to provide the accuracy needed for precise stage movement. The design of the lead screw incorporates several important innovations. Each lead screw is manufactured from Class 12 polished chrome steel. The lead screw is then individually fitted into each assembly with the same level of tolerance being assured for all stages. Any unevenness of surface is kept to less than 0.1 mm. In addition, strict control of the shaft's material and design ensure that any mechanical hysteresis of the stage is minimized.

Translation stage guide

The surface irregularity of a translation stage guide can affect the accuracy of movement. To minimize this a tight tolerance is placed on the fabrication of the surface and the quality of polishing. The maximum size of any imperfections on the surface of the guide is in the order of 0.2 mm. It can be proven that if a ball with a diameter of 4 mm steps into a crevice of 0.2 mm its sag will be approximately 0.005 nm. It will therefore have negligible effect on the performance of the stage.

Straightness of movement

The straightness of stage movement was monitored optically by a laser autocollimator (Figure 2). A mirror, facing an autocollimator, is placed on the moving platform of NTS NanoDirect. The rotational angles of inclination of the mirror in respect to the rotational axes Z and Y were measured during a displacement of 1 mm along the X-axis. The straightness tolerance was better than 1 μm per 1 mm displacement. This parameter shows typically how accurate the grooves of the platform in space are. The guiding grooves on any NTS NanoDirect stage are individually adjusted on an optical bench during assembly and calibration.

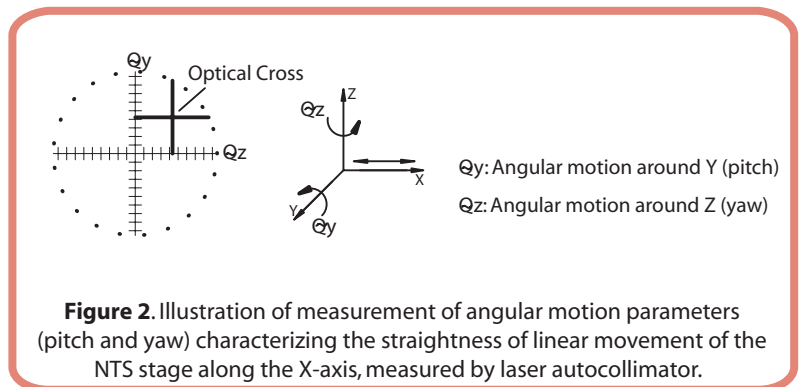


Figure 2. Illustration of measurement of angular motion parameters (pitch and yaw) characterizing the straightness of linear movement of the NTS stage along the X-axis, measured by laser autocollimator.

Bearings

Any surface irregularities in the balls of the bearings or the bearing guides can affect the accuracy with which a demanded movement is achieved. To achieve the optimal requirements the ball bearings used in the stage are Class 12, which sets the spherical tolerance to better than 0.1 mm. The basic parameters that define an individual ball's geometry, and hence its imperfection, are of different signs and are randomly distributed between different balls. Accordingly, a bearing comprising of several balls results in the tolerances being averaged, so that the final inaccuracy resulting from ball geometry uncertainties is less than the worst-case tolerance of a single ball. The NTS10 (i.e. 10 mm travel) NanoDirect stage uses 8 balls in the bearings, which ensures that the effect on accuracy arising from ball imperfections is almost undetectable.

Hysteresis

Hysteresis reflects the difference in the achieved positions, which may occur when the stage is moved to the same fixed point from two opposite directions. One factor, which may contribute toward hysteresis in the stage, is related to a non-optimal lateral tension of the guide ball bearings. If the tension applied is too small this results in a sideways wobbling effect of the stage. Conversely, if the tension applied is too great this can cause increased friction of the ball bearings resulting in a nonsymmetrical drag. The current design overcomes this problem by applying an optimal spring tension, therefore minimizing these effects. A second factor, which may contribute toward hysteresis, is caused by a deviation from colinearity between the shaft of the rotary motor and the lead screw. To correct for this effect the NTS incorporates a proprietary elastic transmission (between the motor shaft and the lead screw) providing orthogonal elasticity of approximately 1 mm/N.

Eliminating backlash

Preloading the lead screw can significantly reduce backlash in the system, by ensuring constant contact between the moving components of the NTS NanoDirect (lead-screw and stage), irrespective of the direction of movement. NTS NanoDirect has two proprietary anti-backlash springs each with 10 N force. This design is only possible because of the very high torque of the rotary piezoelectric motor, which must overcome the spring tension when moving. To avoid any significant wear arising from the high torques used, the NTS NanoDirect is designed with all elements subjected to friction having a hardness of not less than 60 hardness units, HRS by the Rockwell scale.

“Stick-slip” effect

The “Stick-slip effect” is one of the major factors, which limits resolution. The effect is caused by the fact that the coefficient of static friction is greater than the coefficient of dynamic friction. When a driving force is applied to a nanopositioner, movement from rest is slightly delayed on the applied force. Initially, with finite force, there is no movement until the force exceeds the static friction. At this point there is a jump in position. Only “frictionless” devices such as solid-state actuators (piezo actuators) exhibit zero measurable friction and therefore can provide a resolution superior to “classical” mechanical positioners in the sub-micron to sub-nanometer range. However, the NTS NanoDirect series overcomes the “Stick-slip Effect” due to the unique start-stop characteristic of the rotary piezoelectric motor. Any angular position of the rotor is “locked” (held) by the self-decelerating torque of the motor. The same force “locks” the whole friction system of the translation stage. To limit the effect of any jump when initiating motion the unlocking process must occur almost instantaneously (with a time constant in the range of 10-100 μ sec). The incorporated piezoelectric motor has been designed to implement a step formation within 10-50 μ sec per 1 arc sec. This timing results in an angular step of the motor, which translates immediately into an equivalent linear step in the nano-range eliminating any static friction effects.

Interplay of open and close loop system design

An optical encoder is placed on the shaft of the piezoelectric motor providing a linear accuracy of about 0.125 μ m in a closed-loop mode. The shaft lead-screw system is implemented through a special elastic transmission with a twist level of 1 arc sec, which corresponds to 0.4 nm in linear units. The accurate positioning in the nano-range requires step calibration on the adjusted markers of the encoder and the subsequent step interpolation in open-loop mode between the markers.

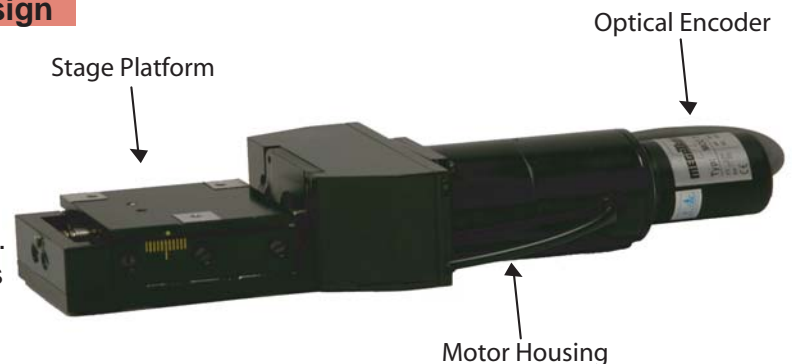
NTS NanoDirect DSP-based controller and software incorporates a proprietary algorithm, which allows the value of the minimum step of approx. 0.4 nm to be measured and updated in real time during implementation of a movement. In this way NTS NanoDirect assures the necessary resolution in open-loop mode between the readings of the optical encoder.

Minimum incremental step of the stage

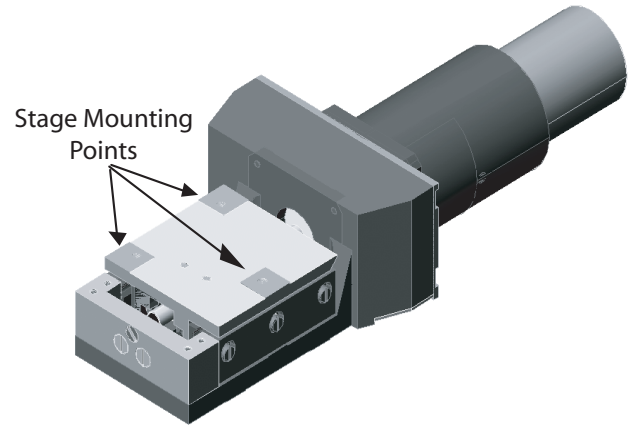
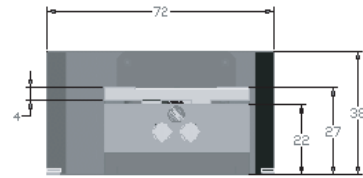
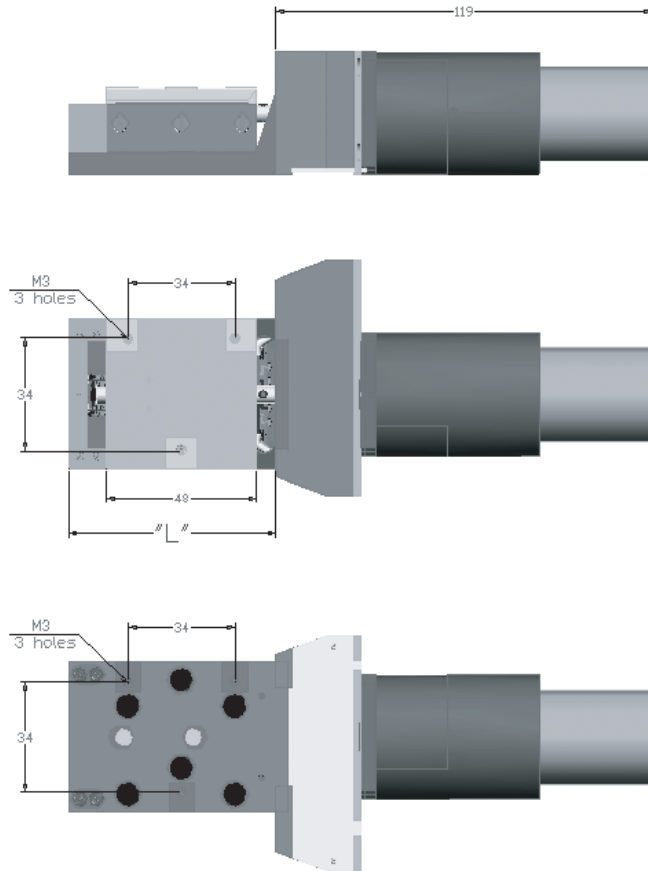
With the combination of all the factors outlined above which affect the intrinsic resolution, the NTS NanoDirect can achieve an unprecedented minimal step size in spite of its long travel range. Using an optical microscope, 2500 minimum steps of the NTS NanoDirect have been routinely measured and found to equate to 1000 +/- 500 nm, yielding a mean incremental step magnitude of 0.4 +/- 0.2 nm.

Manufacturing and quality procedures

NTS NanoDirect is manufactured under strict control of all material and fabrication processes. Every NTS NanoDirect unit is assembled individually on an optical bench and set up with the aid of a precision optical autocollimator and high magnification microscope. Quality control does not permit any of the basic characteristics outlined in these notes falling outside of the tolerances imposed upon them, during production and final test.

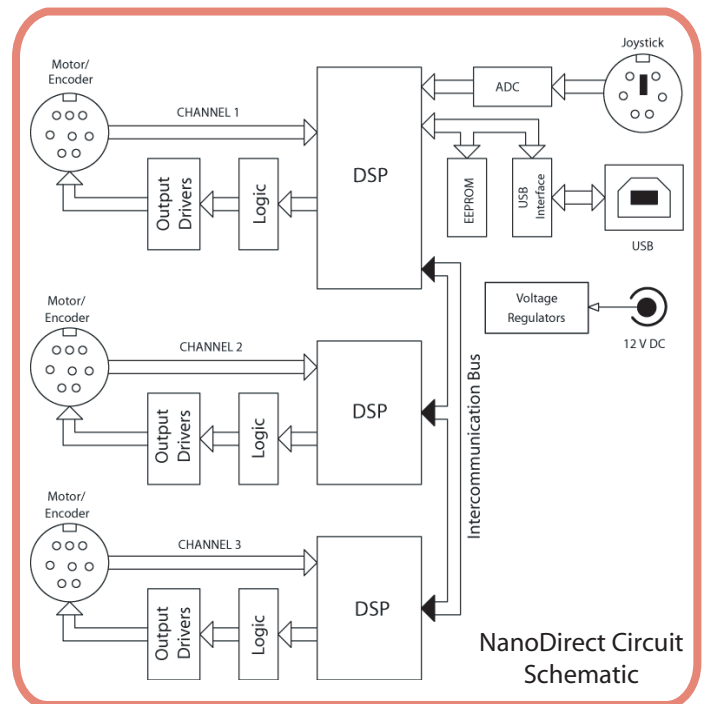


Technical Data



Technical drawings of the NTS stage
Dimensions in mm (L = 66 mm for NTS10)

	NTS10	NTS25	NTS100
Travel Range	10 mm	25 mm	100 mm
Open-Loop Resolution	Approx. 1 nm*		
Min. Close Loop Setting	50 nm (50 Encoder Model) 125 nm (125 Encoder Model)		
Full Travel Range Accuracy	< 0.03% of FS	< 0.03% of FS	< 0.01% of FS
Unidirectional Repeatability	< 1 nm		
Bi-directional Repeatability	< 0.5 μm		
Backlash	< 0.5 μm		
Hysteresis	< 0.5 μm		
Pitch (\curvearrowright) / per 1 mm	< 25 μrad	< 25 μrad	< 2.5 μrad
Yaw (\curvearrowleft) / per 1 mm	< 25 μrad	< 25 μrad	< 2.5 μrad
Nominal Velocity	500 μm/sec **		
Reaction Time (demand to maximum velocity)	< 0.3 msec		
Velocity Range (Stepped – Continuous)	5 nm/sec to 500 μm/sec)		
Max Vertical Load Capacity	3 kg		
Max Horizontal Load Capacity	10 kg		
Max Push/Pull Force	10/50 N	30/30 N	30/30 N
Supply Voltage	12 Volt		
Nominal Power Consumption	6 W		
Length	200 mm	225 mm	280 mm
Weight	0.55 kg	0.65 kg	1.85 kg
Long Term Stability – Drift	< 2 nm /hour @ 20°C		
Recommended Controller	NTS NanoDirect series 1, 2 or 3 channel		
* Contact DTI			
** Contact DTI for custom requirements			



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