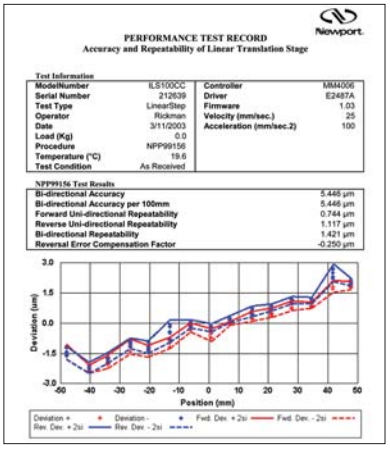
Motion Control Metrology

For over 30 years the Newport Resource has been the reference standard used by researchers, scientists and engineers to advance their technologies, discoveries and products. In today's world of shrinking feature sizes, higher accuracy and resolution requirements and nanometer scale devices it is critical to use the highest quality components available. That is why Newport provides testing and test data for on-axis accuracy, repeatability and trajectory errors (e.g. Pitch and Yaw for linear stages and Wobble and Eccentricity for rotation stages) on every IMS, ILS, MTM, UTM, MFA, VP, RGV, RV, URS, URM, PR/SR, LTA and CMA product sold. A sample test data sheet can be found in Figure 1 below.


PERFORMANCE TEST RECORD
Accuracy and Repeatability of Linear Translation Stage

Test Information

ModelNumber	ILS100CC	Controller	MM4006
Serial Number	212639	Driver	E2487A
Test Type	Linear/Step	Firmware	1.03
Operator	Rickman	Velocity (mm/sec.)	25
Date	3/11/2003	Acceleration (mm/sec.2)	100
Load (Kg)	0.0		
Procedure	NPP99156		
Temperature (°C)	19.6		
Test Condition	As Received		

NPP9156 Test Results

Bi-directional Accuracy	5.446 µm
Bi-directional Accuracy per 100mm	5.446 µm
Forward Uni-directional Repeatability	0.744 µm
Reverse Uni-directional Repeatability	1.117 µm
Bi-directional Repeatability	1.421 µm
Reversal Error Compensation Factor	-0.250 µm

Deviation (um)
Position (mm)
Deviation +
Deviation -
Fwd. Dev. +2si
Fwd. Dev. -2si
Rev. Dev. +2si
Rev. Dev. -2si

Figure 1: Example Test Report

In our continuing efforts to provide the best technical information and solutions to the scientific industry we have expanded many of our product specifications to reflect the true performance users can expect from our products, presented as "guaranteed" and "typical" specifications.

This Motion Control Metrology Primer provides a thorough discussion of what these guaranteed and typical specifications mean, how they are derived and verified, and how they may impact your system performance. The goal of this primer and our motion tutorial is to provide our user community with an understanding of motion specifications that allows them to select the best solution for their application. This primer will provide the reader with an understanding of how the specifications are derived, which is more valuable than simple numerical values alone. Understanding how the specifications are derived often provides a more realistic presentation of the true performance of a product and can help you win the "specmanship" game.

We thank you for your support these past 30 years, and for the trust you put in us to provide you with the very best precision motion products and support.

— Newport's Precision Motion Team

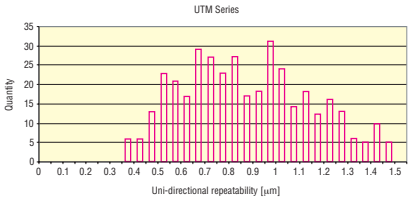
New Performance Specifications

Newport's "Guaranteed" Specification

Although not explicitly stated in the past, our motion products have always been held for release until their specifications could be "guaranteed". These specification values are the maximum performance values, or amount of error, users can expect for this particular product as tested per Newport's A167 Metrology Test Procedure. Any motion products tested that exceed these "guaranteed specifications" is either re-worked or scrapped.

Newport's "Typical" Specification

Typical specifications have been provided for our most popular motorized products and are based upon statistical test data obtained during years of production acceptance testing. The typical values shown can be considered to be the "mean" performance values for that particular specification, and for some



stages the statistical test data is presented. This specification provides the users with a more realistic description of the performance of a particular stage family. For instance, the UTM series stages have a guaranteed Uni-Directional Repeatability specification of 1.5 µm but in reality our historic testing has shown this stage typically provides 0.9 µm typical performance.

Newport's Motion Control Metrology

As mentioned above, Newport provides test data for on-axis accuracy, repeatability and linear/rotational errors on every IMS, ILS, MTM, UTM, MFA, VP, RGV, RV, URS, URM, PR/SR, LTA and CMA product sold. Because the final performance of a positioner depends on many factors in the manufacturing process, such as the precision of machined parts or tolerances in the assembly, a rigorous quality control and metrology procedure is the only way to guarantee that a stage or actuator meets its published specifications.

Newport's internal metrology procedure is a very comprehensive combination of other widely known procedures including ASME B5.57 and ISO 230-2. The following are the major components of our test procedure to demonstrate how we are able to assure our customers receive only the highest quality products:

- **Controlled test bench data taken for 21 measurement points distributed over the full travel of the stage.** This high number of measurement points ensures that we carefully identify the characteristics of the stage along its entire travel range. A typical positioner may perform very well along specific points along its travel, but it might have significantly different characteristics at other points due to imperfections in the bearings or in the drive screw. Procedures that collect only a few data points, 4 or 5 for example, do not accurately represent the true performance of the positioner and may not truly meet published specifications along its full travel range. Newport's dedicated test room for all metrology control processes is temperature stabilized to 19.5°C +/-1.5°C. All stages undergoing testing are stored in the room for at least 12 hours for stabilization before the actual measurements are taken. A certified third party metrology institute provides regular calibration of the test tools to guarantee the highest precision possible.

- **Controlled test bench data taken for 4 complete cycles of motion, in both directions.** This element is not only essential to verifying the repeatability and reversal errors of the positioner, but also to provide a more precise qualification of positional accuracy. This type of test also confirms that the characteristics of the positioner are consistent and eliminates any "lucky" test results.

These two tests combined provide 168 points of data that are used to determine the positioners true performance. The statistical methods used to evaluate this data are presented in Figure 2 below.

- These statistical methods equate to stated specifications, which are the MAXIMUM **Uni-Directional Repeatability, the MEAN Reversal Value and the MEAN Bi-Directional On-Axis Accuracy**, which provide the best representation of true positioner performance that users can expect from repeated use of the product.
- **Uni-directional repeatability is specified at a factor of 3 standard deviations (3-sigma).** The standard deviation is calculated from the positioning data taken at all 21 measurement points in the forward and reverse directions. With 4 cycles of motion, this makes a total of 168 data points. The high number of data points and the 3-sigma approach provides a very accurate indication of the worst-case repeatability with 96% certainty. This means when moving to the same position hundreds of times, 96% of the moves will be repeatable within the specified span.
- NOTE: It is important to clarify that Newport specifies their positioning products as the "guaranteed worst-case repeatability" as opposed to some companies that specify a RMS or mean repeatability to make their data look more impressive. RMS or "mean" repeatability is the expected repeatability error when moving to the same position many times. It converts to only a 1-sigma specification certainty. This significant difference means that when comparing a product with a mean RMS repeatability of 0.5 µm this same product would have a 1.5um specification using Newport's A167 procedure, which is more representative of the actual performance of the product.

	Positive direction	Negative direction
Inaccuracy #*i* at position *j*:	$x_{ij\uparrow}$	$x_{ij\downarrow}$
Average inaccuracy at position x_j:	$\bar{x}_{j\uparrow} = \frac{1}{z}\sum_{i=1}^{z} x_{ij\uparrow}$	$\bar{x}_{j\downarrow} = \frac{1}{z}\sum_{i=1}^{z} x_{ij\downarrow}$
Standard deviation at position x_j:	$s_{\uparrow} = \sqrt{\frac{1}{z-1}\sum_{i=1}^{z}\left(x_{ij\uparrow} - \bar{x}_{j\uparrow}\right)^2}$	$s_{j\downarrow} = \sqrt{\frac{1}{z-1}\sum_{i=1}^{z}\left(x_{ij\downarrow} - \bar{x}_{j\downarrow}\right)^2}$
Uni-direction repeatability:	$R = 3 \bullet \bar{\bar{s}} = 3 \bullet \frac{1}{21}\sum_{j=1}^{21} \bar{s}_j = 3 \bullet \frac{1}{21}\sum_{j=1}^{21} \frac{s_{j\uparrow} + s_{j\downarrow}}{2}$	
Reversal value:	$B = \frac{1}{21}\sum_{j=1}^{21} B_j = \frac{1}{21}\sum_{j=1}^{21} \bar{x}_{j\uparrow} - \bar{x}_{j\downarrow}$	
Accuracy:	$P_{abs} = \left\lvert \mathrm{Max}_j(\bar{x}_j) - \mathrm{Min}_j(\bar{x}_j) \right\rvert = \left\lvert \mathrm{Max}_j\left(\frac{\bar{x}_{j\uparrow} + \bar{x}_{j\downarrow}}{2}\right) - \mathrm{Min}_j\left(\frac{\bar{x}_{j\uparrow} + \bar{x}_{j\downarrow}}{2}\right) \right\rvert$	

Figure 2

- **100 data points are taken for pitch and yaw of linear stages, and wobble and eccentricity of rotation stages using a Newport LDS1000 autocollimator.** These data points are taken dynamically, on the fly, along the travel. The performance specification presented in the test report is the true magnitude of the error (the difference between the max and min error).
- **NOTE: Wobble and eccentricity values of rotation stages are measured during 2 full rotations.** Taking data during one rotation only will not detect all the linear errors as the bearings rotate at only half the speed of the stage.
- **All test tools are mounted on the center of the carriage at a height of approx. 50 mm, which closely mimics typical applications.** Repeatability, reversal value, and accuracy for linear stages are measured in comparison to a calibrated laser interferometer. Repeatability, reversal value, and accuracy on rotary stages are measured in comparison to a high accuracy rotary encoder that is coupled to the rotating platen of the stage.
- **Test reports for every IMS, ILS, MTM, UTM, MFA, VP, RGV, RV, URS, URM, PR/SR, LTA and CMA product,**(as shown in Figure 1) are supplied **AT NO ADDITIONAL COST** to our customers. These test reports not only verify the performance of our products, but they also provide sufficient detail to allow users to improve the performance of their positioning products through backlash compensation, error mapping or linear compensation.

In today's high precision environments it is imperative to have a clear understanding that **the origin of the motion control specifications and how they are actually obtained is ultimately more telling than the numerical value itself.** The old practice of evaluating products based solely upon product catalog specifications – such as repeatability, accuracy, pitch, roll, and yaw as supplied by the manufacturer, can be a very risky way to choose a product – especially in the submicron performance range.

Upon request, Newport can provide historical test data for review for most of its motorized positioners. For more information on Motion Control specifications and technology please review our Motion Control Tutorial and our Application Notes at www.newport.com - or contact your local Newport applications expert.