



LASER TRACKER FIELD TEST SYSTEM

User Manual





LASER TRACKER FIELD TEST SYSTEM

User Manual



Brunson Instrument Company

8000 E 23rd Street
Kansas City, MO 64129

www.brunson.us
info@brunson.us

Tel (816) 483-3187

Fax (816) 241-1945

Thank you for purchasing KinAiry. Remember that our customer support does not stop after shipment of a product—we are here to help you with any measurement challenges that you may have.

TABLE OF CONTENTS

pg. 5	What is KinAiry?
pg. 5	Meet the ACME LT-1 Laser Tracker
pg. 6	Legend

Chapter 1: Getting Started

pg. 8	Precautions
pg. 8	Safety
pg. 8	Use
pg. 8	Residual Risks
pg. 9	Installing KinAiry Software
pg. 11	Hardware Assembly

Chapter 2: Software Features

pg. 13	User-selectable Test Modes
pg. 14	My Tracker List
pg. 14	Uncertainty Values
pg. 15	User Preferences
pg. 16	Pre-test Setup Geometry Check
pg. 17	Post-test Compliance Report
pg. 18	Save / Open Evaluation Data File
pg. 18	Export Error Graph Image
pg. 19	The Data Tabs
pg. 19	Define Tab
pg. 20	Evaluation Tab
pg. 21	Results Tab

Chapter 3: Software Test Modes

pg. 22	Test Mode: Guided Walkthrough
pg. 23	Test Mode: Create Data Template
pg. 24	Test Mode: Import Data File
pg. 24	Test Mode: Create SA Interface

Chapter 4: System Care

pg. 25	Caution
pg. 25	Daily Care
pg. 25	Seating the Kinematic Mounts

TABLE OF CONTENTS continued

pg. 27	Appendix A — How to Export Data Points from BuildIT
pg. 28	Appendix B — How to Export Data Points from CAM2
pg. 30	Appendix C — How to Export Data Points from Metrolog X4
pg. 31	Appendix D — How to Export Data Points from Polyworks
pg. 32	Appendix E — How to Export Data Points from SpatialAnalyzer®
pg. 33	Appendix F — How to Export Data Points from Verisurf X8
pg. 34	Appendix G — Explanation of the Calibration Process
pg. 34	Pre-Calibration Alignment
pg. 37	Taking the Calibration Measurements
pg. 38	Appendix H — The Interim Test Procedures
pg. 41	Results
pg. 41	Traceability
pg. 42	Appendix I — Uncertainty Budget
pg. 42	Uncertainty Budget Components
pg. 44	Summary
pg. 44	Warranty
pg. 45	References

WHAT IS KINAIRY?

KinAiry is a laser tracker and laser radar evaluation system, designed to support the interim testing process defined by NIST (IR-8016), the ASME standard (B89.4.19-2021 Appendix F), and the ISO Standard (ISO 10360-10:2021 Annex E). It guides you step by step, providing confidence that your tracker is performing within expected norms. KinAiry is comprised of a carbon-composite, stable length artifact, KINematically mounted at its AIRY points to a heavy duty rotary positioning device. The KinAiry solution is complete with data analysis and procedural guidance software.

The interim field test is designed to be quick, easy to learn, and yield consistent performance feedback. The role of interim testing is to evaluate instrument performance and errors under the same conditions as the measurement job, answering the question, “How is my tracker performing right now?” Results from interim testing can be used as part of a quality system, to double check instrument performance prior to critical measurements, and to track instrument performance over time. The test’s target positions and artifact orientations have been carefully selected and justified to be sensitive to known error parameters, but the test is sufficiently brief to be accomplished in less than one hour (generally 30 minutes or less).

KinAiry’s innovative, 2.3m long reference length artifact was designed to minimize sensitivity to gravity, fixturing forces, and other factors which affect stability of a calibrated length. And, it’s portable for deployment in the field. The reference length is calibrated using the range measurement capability of the laser tracker, with the calibrated value being established as a part of the test procedure.

KinAiry software leads you through the interim field test and analyzes that data. It also has test validity checks, and calculates MPEs (maximum permissible errors) for each measured point using the laser tracker manufacturer’s MPE coefficients.

MEET THE ACME LT-1 LASER TRACKER

The tracker that you see pictured throughout our manual is the **ACME LT-1**. No, it’s not the latest device ordered by Wile E. Coyote to foil his road-running adversary. It’s the fictitious creation of the fertile minds in our engineering department. Our make-believe tracker features IFM along with ADM measuring capabilities, and comes complete with made-up MPE values.



SYSTEM COMPONENTS



1. Positioner
2. Mirror and Holder
3. KinAiry Software Flashdrive
4. Spanner Wrench
5. EasyConnect® Base
6. Two Retroreflector Counterweights



LENGTH ARTIFACT DETAIL



Back of Artifact Bar

Side view of Positioner

1. Carry Handles
2. Target Nests
3. Counterweight Nests
4. Mirror Mount
5. Mirror Adjustment Screws
6. Ring Mount (*on back*)
7. Hand Wheel (*on back*)

CHAPTER ONE: GETTING STARTED

Precautions: Safety

- KinAiry is designed for use on flat, level floor surfaces. Deploying the length artifact on an unsuitable stand or on non-level surfaces increases the tipping hazard.
- Prior to transport, always remove the length artifact and positioner from the stand and place them in the provided cases.
- The length artifact is very long when fully assembled (8 feet/2.5m). When mounting and dismounting the artifact, pay attention to provide necessary clearance for its entire length to reduce the possibility of damage to either the artifact or the surroundings.
- The stands should be handled according to procedures in their respective owner's manuals.
- The artifact and positioner are heavy. Use proper lifting techniques when mounting/dismounting or transporting to prevent injury.
 - Positioner – 24.6 lbs (11.2 kg)
 - Length Artifact – 32.7 lbs (14.8 kg)
 - Case (packed) – 95 lbs (43.1 kg)

Precautions: Use

- As part of its function, the length artifact rotates between horizontal and vertical orientations.
- Ensure the stand is at sufficient height (> 4 ft) to allow clearance of the length artifact from the floor when rotated into the vertical orientation.
- Confirm that in the vertical orientation, the artifact will not contact the ceiling or fixtures on the ceiling, lighting, HVAC, etc. (height of tracker + 4 ft).
- Keep people and equipment clear from the path of rotation to prevent injury and equipment damage (circle, diameter 8 ft).
- The bearing housings supporting the rotating section are partially open, and present a pinch hazard. Keep hands, fingers, hair, and clothing clear of the rotating assembly.

Precautions: Residual Risks

Though precautions have been taken to identify and minimize risks to operators and equipment, some additional residual risk remains when handling long and heavy fixtures. To manage these inherent risks, operators may wish to use safety shoes to protect against drops as well as the use of a spotter to help identify clearance or safety issues when handling the equipment.

Required Equipment

The following items are required to run the interim field test and ISO 10360 with KinAiry. Not all of these items are included with your purchase of KinAiry.

- KinAiry laser tracker evaluation system
- Metrology stand (230 or M-Series recommended)
- One high quality retroreflector (three optimal)
- Computer to run KinAiry software
- Tracker being tested

Installing KinAiry Software on a Windows Machine

KinAiry software is designed to teach users how to conduct the interim field test procedure, compile data, and organize the results. Minimal computer system requirements are:

- Windows 10 or 11, 32- or 64-bit
- 2.6GHz Processor
- 4GB RAM
- USB Port for software installation

Be sure you are logged in as an administrator when installing the software. KinAiry's program data folder (e.g., C:\ProgramData\Brunson KinAiry) will be defined with read/write permissions for all users at the time of installation.

Insert the jump drive into a USB port on your computer. Open the KinAiry folder and double click on the executable file **Setup_x.xx.exe**, where **x.xx** indicates the software revision.

When you double-click the installation file, a security dialog may pop up, depending on the user account control settings on your computer. Click the **Yes** button to allow the changes. Click through the successive dialogs to complete the installation. You must agree to the EULA (end user license agreement) in order to finish.

Note: In order to use KinAiry's SpatialAnalyzer (SA) automation feature, SA must also be installed on the PC.

First Startup

When KinAiry is first started, it searches for a method to authorize the software. Authorization is provided in one of two ways – a “key file”/dongle pairing, or a cloud license (requires internet connection). If neither is found, a License Manager dialog box pops up. This dialog allows you to register a key file (if you are using a dongle) or, alternatively, to activate a cloud license. If the License Manager dialog has been closed, go to KinAiry’s Help menu and select Start License Manager.

Using a dongle: A dongle allows KinAiry to be loaded on any number of machines, and will run as long as the dongle is connected. Any machine using the dongle must also have registered the corresponding key file. If you have received a dongle, there will be a corresponding key file supplied on the USB thumb drive which contained the KinAiry installer file. You can register the key file using the Dongle License menu item in the License Manager dialog, selecting Register Key File.

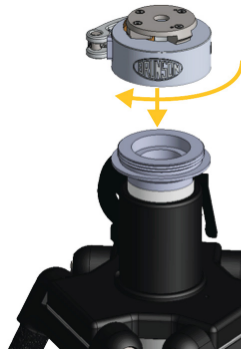
Using a cloud license: If you received activation codes for an online license, you can use the Cloud License menu item, selecting the Activate option. You must have an active internet connection to do this. After that, you can use the software while not connected to the internet, although a connection is required every few days to refresh the license. You will be told if a reactivation will be required in the coming days.

Hardware Assembly

To set up KinAiry, you'll need the 2.3m carbon composite length artifact, EasyConnect[®], spanner wrench, positioner, and a suitable metrology stand. When setting up the system, ensure that all stand joints are securely locked in place. Give consideration to the floor surface, avoiding carpet, vinyl, wood, or spanning large cracks in concrete when possible. Position all components as described below.



Setup the stand and lock all joints.



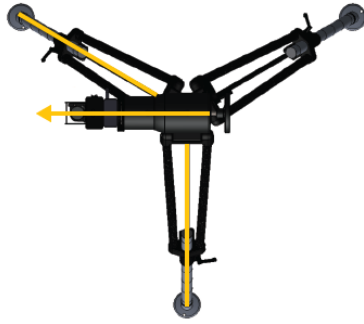
Install the EasyConnect. Tighten it in place using the spanner wrench.



Clamp the positioner in place.



Attach KinAiry bar extensions and tighten thumbscrews.



Orient the positioner to allow clearance between the stand braces/legs and the length artifact as it rotates between horizontal and vertical orientations.



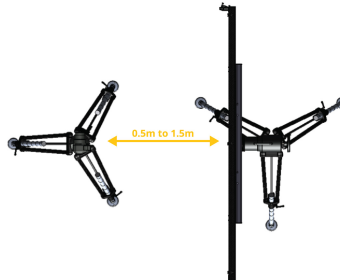
Improper orientation of the positioner may cause contact between the artifact and stand leg during rotation.



Mount the artifact by placing the ring brake into the slot on the face of the positioner.



Rotate the artifact into the horizontal orientation. The ring brake should click into position. Detents are provided at 45° intervals. Clamp the artifact to the positioner by engaging and tightening the hand wheel (6-8 full rotations). The hand wheel must be pushed toward the front of the system to engage the ring brake.



Arrange the tracker according to the interim field test: approximately 0.5m to 1.5m from, and centered on (directly in front of), the length artifact.



At one point in the test, the tracker must be at the same height as the artifact. At another point, the artifact must be 0.5m above the tracker. This 0.5m offset can be established by either lowering the tracker or raising the artifact, or both. Adjust the initial height of the stands so that you can accommodate the 0m and 0.5m offsets during the course of the test.

Note: If you are using one of our M-Series stands to hold the KinAiry artifact, be mindful that its extension tube has 0.5m vertical travel. It is helpful to fully retract the extension tube at the start of the test and position the bar so that it is just above tracker "eye level".

CHAPTER TWO: SOFTWARE FEATURES

User-Selectable Test Modes

The KinAiry software has several unique modes:

- *Guided Walkthrough** – Use this test mode to see a detailed explanation of the test process, with no data capture or data file imports. Pictures and explanatory text guide you through the steps required by the interim field test procedure.
- *Create Data Template** – Use this test mode to create an empty KinAiry data file (in non-proprietary CSV format) using specific test conditions. Output the empty, preconfigured file, and edit it as desired with a text or spreadsheet editor. Reopen the file in KinAiry to view test results.
- *Import Data File* – Use this test mode to import a data file exported by your laser tracker software.
- *Create SA Interface* – This test mode controls the tracker directly through the KinAiry software, streamlining workflow and data analysis. This mode only appears available if SpatialAnalyzer is installed.

* These test modes do not handle data and do not create an error graph.

My Tracker List

Prior to performing the first test on any specific tracker, that tracker's identifying data must be logged into **My Tracker List**, found under the **Tracker** main menu item. At a minimum, you must select the manufacturer and model, as well as enter the serial number for the tracker. Optionally, you can assign the tracker a nickname to help you easily identify the tracker (this can be helpful if you have several). Other items available on this dialog are:

- An edit box for any IP address that is required to communicate with the tracker when using SpatialAnalyzer automation.
- A place for you to record the latest instrument calibration certificate number as an optional convenience for your own use.
- A display of the entered tracker's Maximum Permissible Error (MPE) coefficients, if known. KinAiry calculates the maximum permissible error for each point based on the given point geometry and several MPE coefficients provided by the tracker manufacturer. This calculation follows the instructions laid out by ISO 10360-10^[1]. The MPE coefficients exist in the software for many tracker models, and are not editable by the user.

Uncertainty Values

Under the main menu item Tools, you may select View Uncertainty Values. A number of values have been identified as components of the uncertainty budget when using KinAiry to perform an interim field test. If a tracker has been selected for testing, uncertainty values related to that tracker will also be displayed on this dialog. These uncertainty values drive the uncertainty bars which are displayed on the error graph at the end of a test, with one uncertainty value associated with each error point.

User Preferences

You can define certain user preferences by selecting **Tools** from the main menu, then **Preferences**. Options selected here define certain default values used when the software is opened and a new test is initialized.

The options are:

- *Preferred Working Folder* – Identifies the default working directory for saving or opening files used by KinAiry
- *Significant digits displayed* – Controls how many decimal places are visible on the Evaluation tab where point data is displayed. All values are stored at full precision even though fewer digits may be displayed for clarity.
- *Enable use of legacy key files* – Must be checked if legacy key files (machine ID type) are used for software authentication.
- *Calibration shot repetitions* – Allows you to set your choice of 1, 3, or 6 repetitions of the calibration point-gathering sequence as the default setting.
- *Reflector type* – This dropdown box allows you to select from two different SMR choices as your default selection for a test - either high accuracy (recommended) or standard accuracy.
- *User-defined scale for error graph* – If checked, this allows you to select from a set of predefined scaling choices for the error graph generated by KinAiry. If not checked, KinAiry will select a range for each graph which is large enough to accommodate the largest error data resulting from the given test.
- *Error graph top line value (inches)* – When applying a user-defined scale for the error graph, this control allows you to select the graph range (top line value) that is used when a test is conducted using “inch” units.
- *Error graph top line value (mm)* – When applying a user-defined scale for the error graph, this control allows you to select the graph range (top line value) that is used when a test is conducted using “mm” units.

Also included are several preference options that relate only to the use of KinAiry in conjunction with SpatialAnalyzer (SA):

- *Use 3 SMRs for test* – When checked, the default setting for SA automation tests is to anticipate the use of 3 SMRs (one in each nest) rather than 1 SMR (moved from nest to nest by the operator).
- *Counterweight move prompt* – A dropdown box allowing you to select the number of seconds of delay applied when moving the counterweights in anticipation of the next shot.
- *Beam break timeout* – The length of time in seconds that KinAiry will wait for a beam break during the test process to resolve.
- *RMS threshold (mm)* – Sets an RMS requirement in mm for each point collected by SA. If the tracker is unable to deliver a point to SA with an RMS under or equal to this setting, KinAiry will retry shooting the point.
- *Retries if RMS not met* – The number of times KinAiry will retry shooting the same point, attempting to get a value which has an RMS below the user-established threshold.
- *Point transfer timeout* – The number of seconds that KinAiry will wait for confirmation that a point was transferred to SA from the tracker being tested after the command was given to capture a point. (This is normally not something that the user must worry about.)

Pre-test Setup Geometry Check

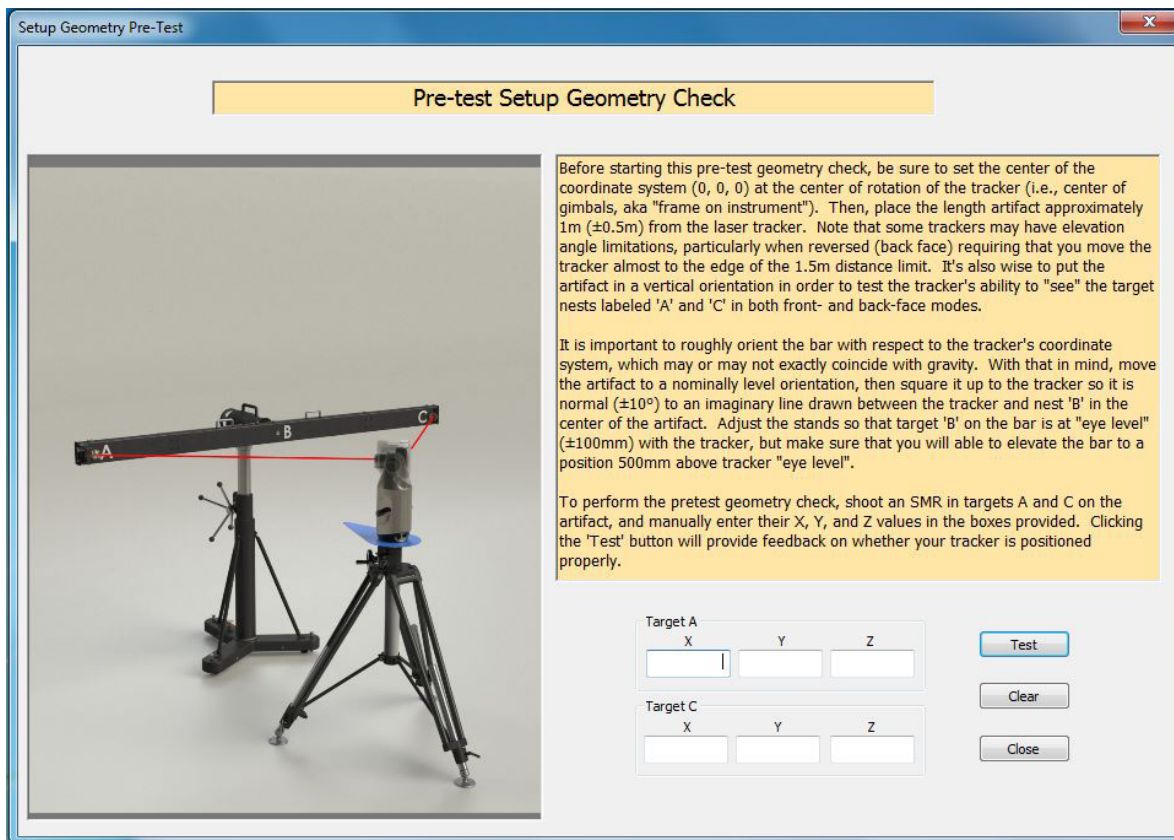
This function allows you to gain confidence that you have positioned the tracker and length artifact properly prior to taking any test points. This function is available by clicking **Tools, Pre-test Setup Geometry Check**. This may be done before any other step, i.e., before “buck-in” or calibration. Simply shoot and enter coordinate point values for the “A” and “C” targets to get clear feedback regarding the bar’s position, including hints on where to move it for proper test results.

Before doing this positioning check (or the full KinAiry test, for that matter) be sure that the center of the coordinate system is defined at the tracker’s center (where the rotational axes meet). This is sometimes called “frame on instrument” or “center of gimbals”.

Also remember that during the test, you will be required to rotate the artifact to a vertical position, and shoot all targets in back-face mode. Some trackers have a difficult time shooting targets which are close to the floor, particularly in back face mode. This sometimes necessitates moving the tracker further from the bar, approaching the 1.5m limit for distance between the tracker and target “B”.

By checking the tracker’s ability to take a back-face measurement close to the floor, and running the pre-test setup geometry check, you can help ensure that the test will run smoothly.

Note that this Geometry Check is automatically included as a normal part of any test conducted using SpatialAnalyzer automation.



Post-test Compliance Report

Test conditions are requirements that must be met in order for the proposed uncertainty budget to be valid, and to preserve the sensitivity of the interim field test procedure. KinAiry monitors these test conditions, and a report is accessible from the main menu under **Tools**. KinAiry's ability to test for certain validity conditions depends upon the origin of the coordinate system being located inside the tracker at or near the intersection of the horizontal and vertical axes. KinAiry software checks for the conditions below.

- *Distance* – The distance of the laser tracker from target B should be $1.0\text{m} \pm 0.5\text{m}$. (This excludes any test step wherein the user is instructed to increase that separation arbitrarily).
- *Yaw Angle* – The length artifact should be perpendicular to a line between target nest B and the aperture of the laser tracker. A deviation up to $\pm 10^\circ$ is allowed.
- *Elevation differential & Artifact level* – All targets on the length artifact must be within a vertical distance of $\pm 100\text{mm}$ from tracker "eye level". The tracker may or may not be oriented perfectly to gravity level, but the artifact should be aligned parallel to the plane of the tracker's coordinate system which is most parallel to the floor (whether it's the XY, YZ, or XZ plane) within this tolerance band.
- *Time* – The test is to be completed within 60 minutes. This error will be triggered if data is altered beyond the allowable time limit. Times are not accessible from within the KinAiry software. Times can be viewed or edited in the CSV data file using a text editor or spreadsheet software.
- *Temperature* – An error will be generated if a temperature field is left blank, or if any temperature deviates more than $\pm 1.0^\circ\text{C}$ ($\pm 1.8^\circ\text{F}$) from the average temperature during calibration.

Save / Open Evaluation Data File

Tests performed in KinAiry are saved in a non-proprietary CSV file format, and reopened later as desired. Saved tests can be used to track instrument performance over time, or confirm results before and after the instrument is serviced. To save a test, use the main menu's **File, Save** or **Save As** functions or the **Save** or **Save As** toolbar button. To view prior test data, or to view data placed in a template file, use **File, Open** from the main menu, or the **Open** toolbar button.

Export Error Graph Image

Once an error graph has been generated by KinAiry, it may be saved in JPG format. The **Export Error Graph Image** function is available in the **Tools** menu.

The Data Tabs

KinAiry has tabs to display or edit information pertaining to any given test. These are the *Define*, *Evaluation*, and *Results* tabs.

Define Tab

Brunson KinAiry

File Tracker Tools Help

Define Evaluation Results

Select Test Type

- ☒ IR-8016 IFT
- ☐ ISO/ASME IFT

Select test mode

- ☐ Guided Walkthrough
- ☒ Create Data Template
- ☐ Import Data File
- ☐ Create SA Interface

Test parameters

Measurement units: Select

Temperature units: Select

Calib. target reps: 3

Retroreflector type: High acc ($\pm 2.5 \mu$)

Tracker used in test

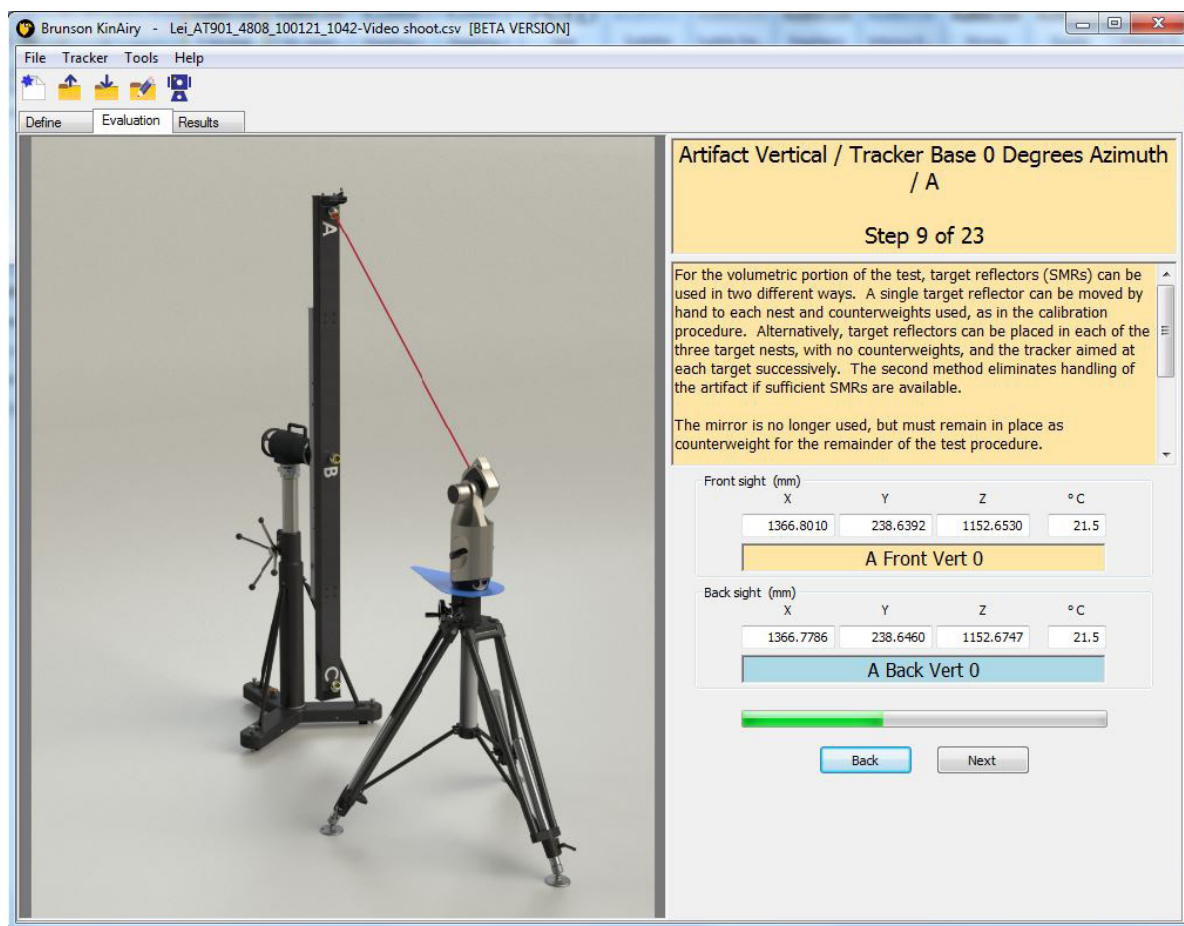
Mfg	Model	SN	ID/Nickname
<input type="checkbox"/> API	Radian Pro	60071	
<input type="checkbox"/> FARO	Vantage	v01001505581	
<input type="checkbox"/> Leica	AT901	4808	
<input type="checkbox"/> Leica	AT960	750871	

Start evaluation process

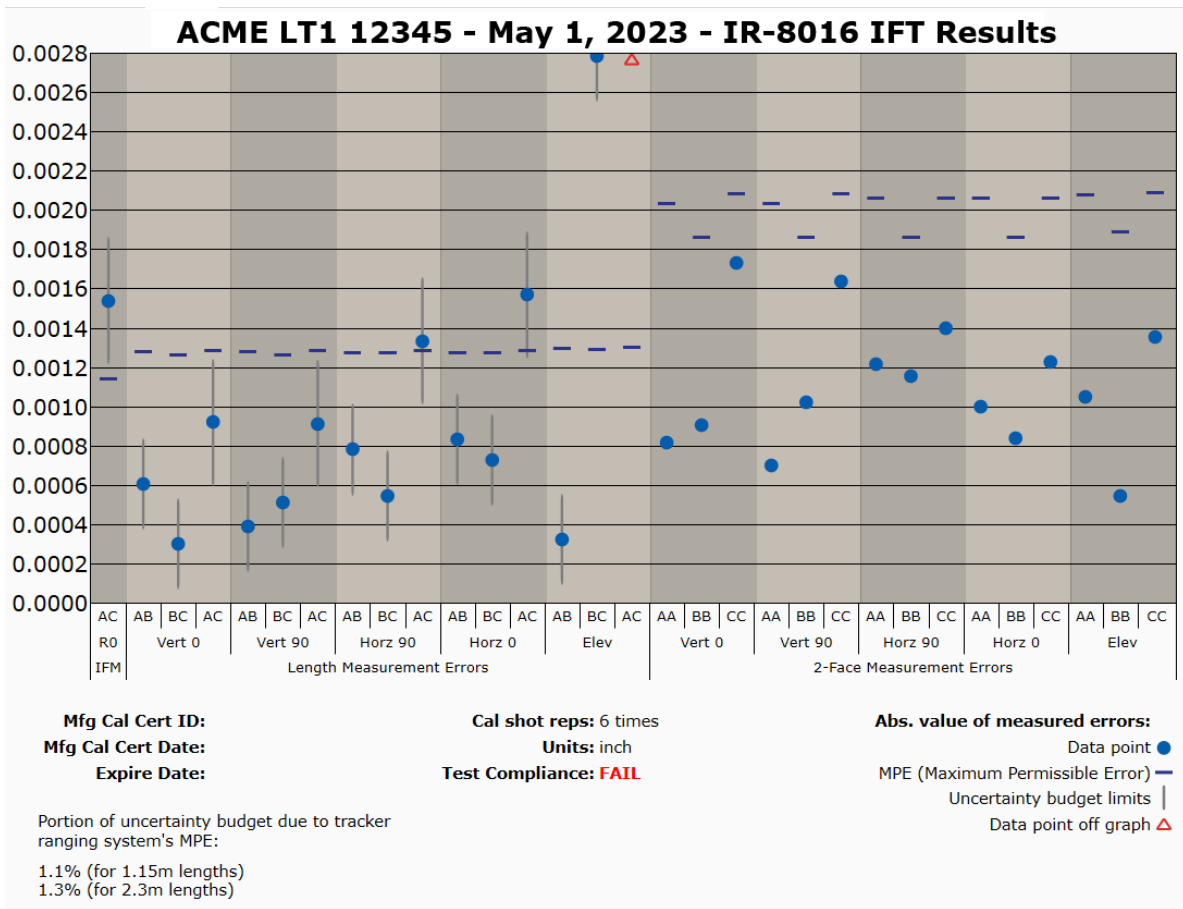
Start

Job Notes

The *Define* tab is where an interim test begins. Here, you can define the test mode, and select parameters relevant to the chosen test mode. The **Start** button begins the test and takes you on to the next steps. While a test is underway, all options on this tab are switched to read-only mode, except for *Job Notes*. *Job Notes* is an edit field that you can use to keep any information relevant to the evaluation that's underway.



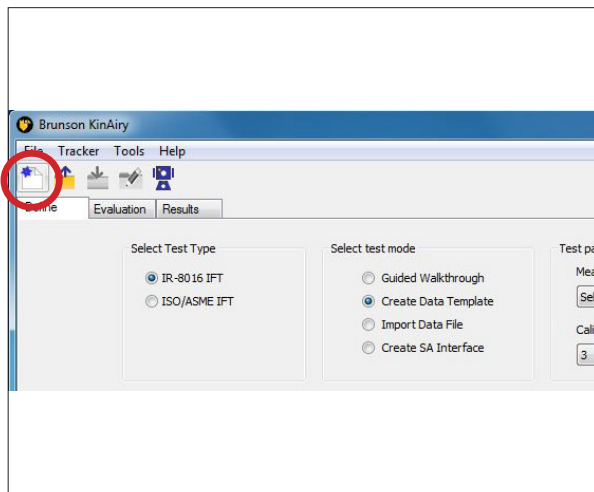
When in *Guided Walkthrough* test mode, the *Evaluation* tab may be used to step through the setup, alignment, calibration, and data capture segments of a test. It provides pictures and descriptions of the various artifact positions required by the test. The **Back** and **Next** buttons allow navigation through the test sequence. Additionally, when viewing an existing KinAiry test file, coordinate data for each step of the test will be displayed on the *Evaluation* tab.



The *Results* tab displays an error graph visualizing results for the interim field test or ISO 10360-10. The title contains the name of the test procedure, the make, model and serial number of the tracker under test, and the date the data was last modified. The scale on the vertical axis indicates magnitude in millimeters or inches. Labels on the horizontal axis identify each data point by test orientation. Horizontal blue bars on the plot represent the MPEs for each measurement. MPEs are calculated according to ISO 10360-10^[1] using the actual coordinates for that particular error. On the left half of the plot, measured error points are displayed as dots with vertical uncertainty bars. The uncertainty bars refer to the combined expanded uncertainty of the reference length. See Appendix I for more detail regarding uncertainty. Error values on the right half of the plot do not have uncertainty error bars. They represent two-face errors, and are not compared against any reference length. In the legend below the graph, test information is preserved for later reference. The tracker's certification for the ranging system is referenced as the traceable standard used to calibrate the reference length. Checks for validity conditions are summarized in a list.

A "Post-Test Compliance" report can be accessed by clicking on "Pass" or "Fail" on the "Test Compliance" line.

CHAPTER THREE: SOFTWARE TEST MODES



After launching the KinAiry software, click the toolbar icon for **New Evaluation** (or from the main menu, select **File, New Evaluation**). Then, select the desired test mode using the radio buttons provided. Each test mode will reveal additional items that you can use to configure the test as desired.

In all of the test modes except “Import Data File”, you must choose between 1, 3, and 6 repetitions of the calibration target shots. The uncertainty budget (explained more fully in Appendix I) assumes that one sample is taken. Additional repetitions are not used to decrease the uncertainty budget for the calibrated length, but may reduce the effect of measurement inconsistencies in calibration by using the average of multiple measurements as the best estimate of the true value.

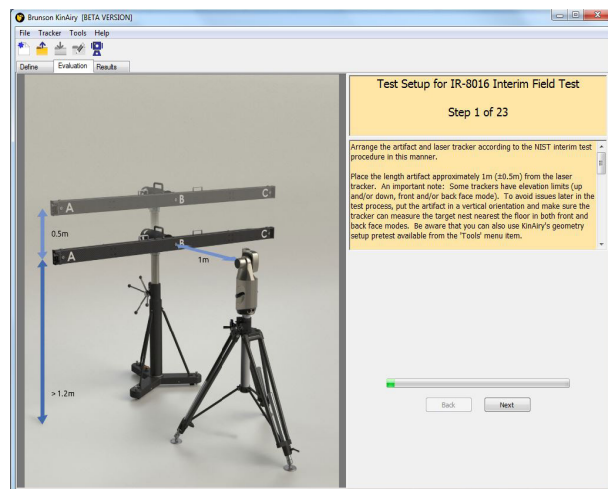
A short discussion of each test mode follows.

Test Mode: Guided Walkthrough

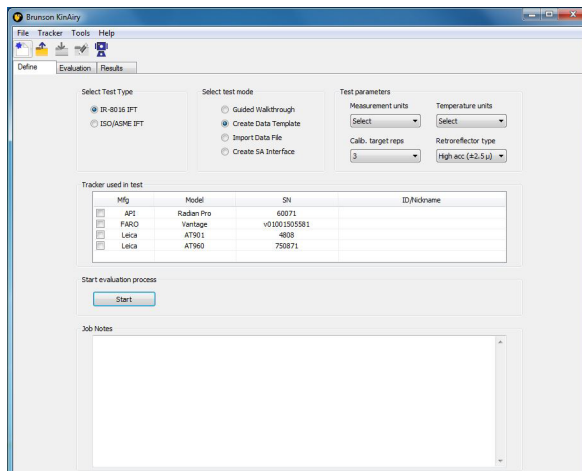
Using the *Guided Walkthrough* mode can be useful for familiarizing yourself with the procedure, or guiding a test where another application is used to collect the data. In this mode, you are responsible for:

- Determining the number of calibration target shot repetitions
- Indicating which type of tracker is being tested.

When you click **Start**, KinAiry will bring the *Evaluation* tab forward. Navigate through the steps with the **Next** and **Back** buttons. Since no data is entered or imported in this test mode, no error graph is generated on the *Results* tab.



Test Mode: Create Data Template



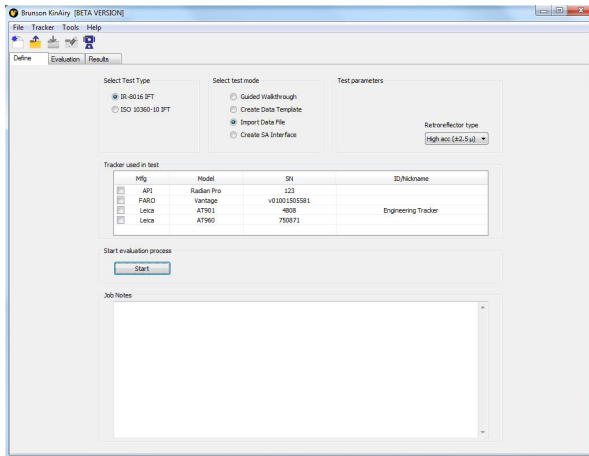
Create Data Template mode gives you an easy way to construct and save an empty KinAiry data file, in the common CSV file type. This non-proprietary file type was chosen to give you convenient access, if direct data editing is desired. This file is most easily edited using a program like Microsoft Excel[®]. The template file will contain a header with identifying information about the test, the given tracker's default MPE coefficients, uncertainty budget values, and a place to edit (or copy/paste) test point data. Once populated with data, the file may be re-opened in KinAiry to view results, check or modify data, and be saved again.

In this mode, you are responsible for:

- Determining the number of calibration target repetitions
- Selecting the measurement units (in or mm)
- Selecting the temperature units (°F or °C)
- Selecting the SMR grade
- Selecting the tracker to be evaluated

If the tracker you wish to test is not shown in the *tracker used in test* box, add it to the list by clicking on the **My Tracker List** icon on the toolbar or by selecting **My Tracker List** from the **Tracker** menu. To create the template, click the **Start** button. KinAiry will open a *Save* dialog in the default file folder location, with a suggested filename. You may use this name or assign your own. Save the data file and access it with an appropriate editor to enter data.

Test Mode: Import Data File



Test data captured using your tracker software can be exported to a file and then read directly into KinAiry software for analysis. For more information on exporting data, and which tracker software programs can export data used by KinAiry, see Appendices A-F.

In this mode, you are responsible for:

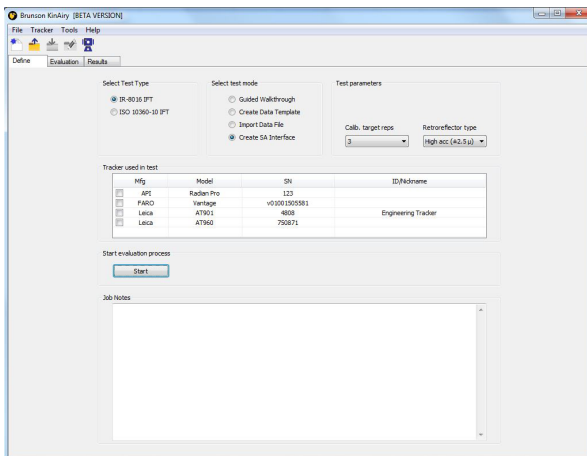
- Selecting the SMR grade
- Selecting the tracker to be evaluated

After selections are made, click the **Start** button. A dialog will open. Navigate to the data file exported from

your tracker software and open it.

After importing the data file, KinAiry will display the results of the test on the *Results* tab. Point coordinates are viewable and editable on the *Evaluation* tab. Save the KinAiry file for your records.

Test Mode: Create SA Interface



KinAiry v2.01 or newer is capable of using SpatialAnalyzer® (Ultimate package) to automate an instrument evaluation. The SpatialAnalyzer option will be enabled if SA is present on the computer.

KinAiry is capable of starting SpatialAnalyzer, and adding your chosen instrument. However, if desired, you can do this yourself before starting a test. Either way, just be sure that your computer can communicate with the instrument's controller.

For any given instrument, SpatialAnalyzer's instrument interface contains a list of measurement profiles which are available for use. During the evaluation, KinAiry must be able to access a measurement profile having specific characteristics. Depending upon the version of SpatialAnalyzer that you are using, KinAiry will do one of two things at the start of an evaluation. If the needed profile is missing from the interface, KinAiry will either append the needed profile to the current list of measurement profiles itself, or will give you instructions regarding how to create or import the needed profile. This action will be repeated each time you start an evaluation with a new make and model of instrument.

Select desired test parameters and follow the guided instructions.

CHAPTER FOUR: SYSTEM CARE

Caution

- Do not attach targets to the artifact other than 1.5-inch spherical retroreflectors used with laser trackers or the supplied counterweights which simulate the weight of a retroreflector.
- Do not attempt to make contact measurements of the artifact (e.g., using a portable CMM arm).
- Do not hang or attach anything to the system other than what is described in this manual. Although the carbon tube is very strong, it has very fine mounting connections which may be damaged by misuse.
- Lift and carry the length artifact ONLY by the two built-in handles. Do NOT carry the length artifact by holding the carbon composite bar.

Daily Care

- Keep the KinAiry hardware clean, dry, indoors, and away from harsh chemicals.
- The length reference artifact (carbon composite tube and the attached aluminum tube) should be handled gently to ensure optimum performance. It should never be located anywhere other than in its case or mounted on the positioner.

Seating the Kinematic Mounts

KinAiry's carbon composite length artifact rests on kinematic mounts. These mounts attach it to the aluminum support tube. As you face the artifact, you will see two sets of four socket cap screws. These are the two kinematic attachment points, and as you might expect, each one has a different internal configuration. While designed for durability, the kinematic mounts are nonetheless susceptible to abuse through mishandling. This is the main reason you should not pick up the bar by anything other than the two handles provided.

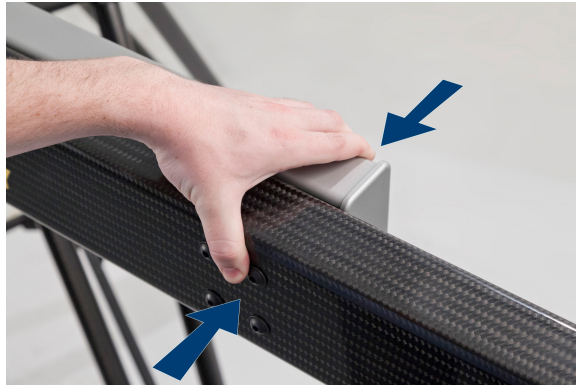
Also as you'd expect, the kinematic mounts allow the carbon and aluminum tubes to remain connected while moving independently of each other, with the mounts having a favored home position. This home position allows the carbon tube to float on the aluminum tube, relieving the fixturing stress that might otherwise exist.

It is possible (by shipping or rough handling) for one of the mounts to be moved to something other than its home position. If this happens, it must be reseated. This is easy to do.

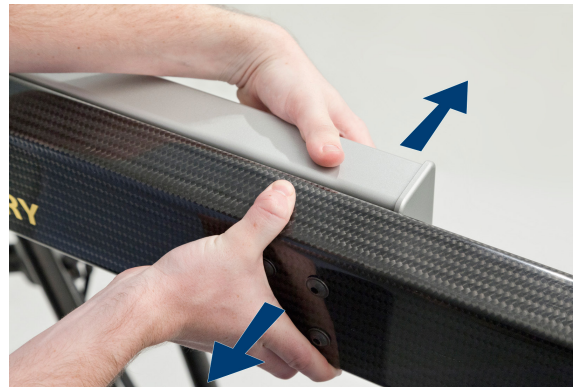
Do this learning exercise once or twice to get the feel of the mounts. The process is different for both mounts. Once the length artifact is mounted securely to the positioner, do the following:



For the AB mount, located between target nests A and B: Squeeze the carbon tube together with the aluminum tube sufficiently to feel motion. Then release. The kinematic mount should click into place, ensuring that it has been properly seated.



For the BC mount, located between target nests B and C: Again, begin by squeezing the carbon and aluminum tubes together. However, you may not feel any motion. (If you don't, the mount is not in its home position.)



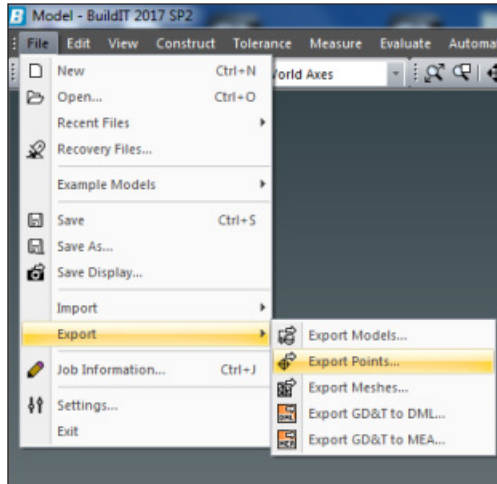
Follow this action by pulling the two bars apart. Again, the BC kinematic mount should click into place, now being properly seated.

We don't recommend that you go through this process each time you set up the bar. It is just an exercise so that you'll know how the mounts should feel when seated in their home position. Rather, you should know that the AB kinematic mount will always be in its home position unless the mount itself fails. The BC mount is the one susceptible to being moved out of home position through rough handling or shipping. Generally, all you need to do is hold the end of the carbon bar (at the C end), and wiggle or twist it gently. If it is not in its home position, you will be able to feel some motion, indicating that it is not seated in its home position. If this happens, twist the carbon tube or pull the tubes apart, as you did above, to reseal the AB kinematic mount.

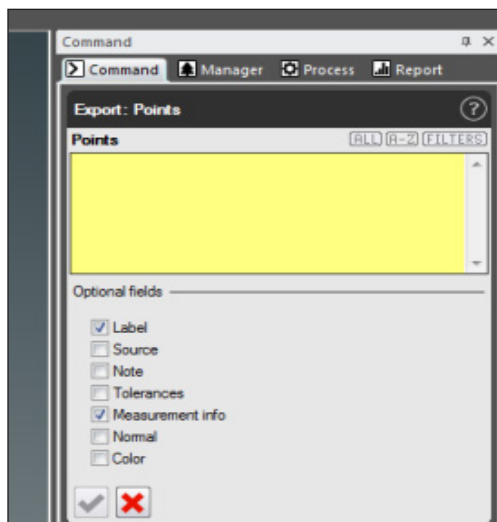
If you experiment a little you will understand the feel of the mounts and be able to quickly tell whether the AB mount is seated, while still treating the length artifact gently.

APPENDIX A: HOW TO EXPORT DATA POINTS FROM BUILDIT

To prepare a data file for export to KinAiry using BuildIT, begin by taking the points in the same order as presented in KinAiry Guided Walkthrough mode.



From the menu, select **File, Export, Export Points**.

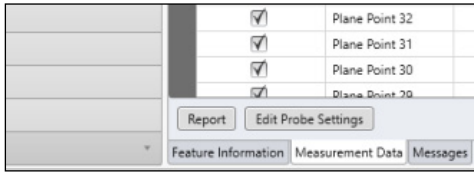


BuildIT will open a dialog window for you to select the points to export. Select **All** and Sort **A-Z**. The default label and measurement info is all that needs to be selected. Press the green check mark to create a data file. Save the file in a location convenient to access from KinAiry software.

Open the file and verify that the points are in the order they were taken. Close the file and import it using KinAiry software, **Import Data File** function.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	#												
2	# Point Export from BuildIT Software												
3	#												
4	# BuildIT File: No BuildIT File												
5	# Date/Time: Thu Jun 22 10:54:37 2017												
6	# User: tracker												
7	# Active CS: World Axes												
8	# Active Units: in												
9	#												
10	# "Point Name"	"X"	"Y"	"Z"	"Source"	"Probe O"	"RMS Errc"	"Samples"	"Tempera"	"Pressure"	"Humidit"	"Device N"	"Date/Tin"
11	Point1	82.31772	25.31816	-13.2681	"User: tra	0.75	0.003517	100	69.98	979.395	64.8	"Device1"	"Thu Jun : "
12	Point2	82.31809	25.3176	-13.268	"User: tra	0.75	0.003215	100	69.98	979.395	64.8	"Device1"	"Thu Jun : "
13	Point3	82.31866	25.31775	-13.2674	"User: tra	0.75	0.004614	100	69.98	979.395	64.8	"Device1"	"Thu Jun : "
14													

APPENDIX B: HOW TO EXPORT DATA POINTS FROM CAM2



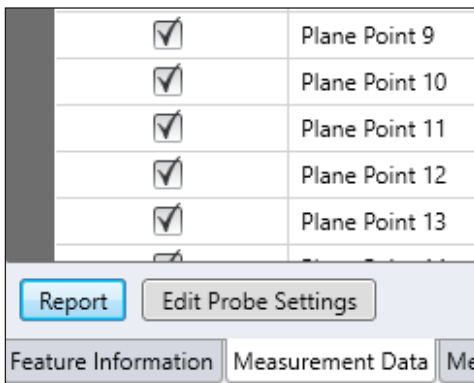
Using CAM2, capture test data as demonstrated in the Guided Walkthrough. Then switch to CAM2's **Measurement Data** tab.

Feature	ID	x	y
Circle 1	1	73.429mm	-85.365mm
Circle 1	2	73.365mm	-95.342mm
Circle 1	3	75.034mm	-105.744mm
Circle 1	4	79.216mm	-116.895mm
Circle 1	5	82.005mm	-126.723mm

Drag & Drop to arrange the data table as instructed below. Dropping a column header outside of the table will delete it. Right-clicking on a column header will lead to the **column chooser** to add a column.

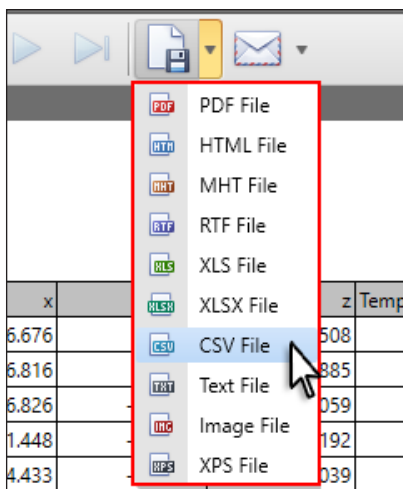
Data MUST be in order left to right as stated below.

1. Feature
2. X
3. Y
4. Z
5. Temperature
6. Time Stamp



The point order MUST remain in the same chronological order as taken in the KinAiry guided walkthrough.

After formatting click the **Report** button. A new Print Preview window will open.



In the upper right hand corner of the print preview use the drop down shown to the left to export a **CSV file**.

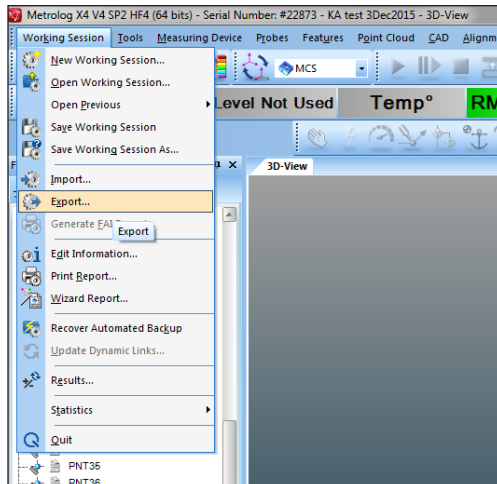
Import the CSV file using KinAiry software, **Import Data File** function.

APPENDIX B: HOW TO EXPORT DATA POINTS FROM CAM2 (CONTINUED)

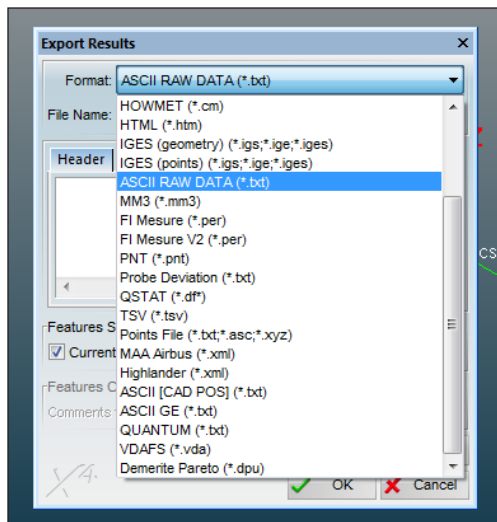
WARNING: Some versions of CAM2 export a *.csv file with a time stamp of this format: hh:mm:ss.ddd. Notice that this includes decimal seconds. A problem can arise if you open the exported *.csv file with Excel and then save it again before importing into KinAiry. If Excel opens a *.csv file and finds a cell which appears to contain a time value, but having digits to the right of a decimal point, it can default to a mm:ss.ddd format for that cell. This will unceremoniously lop off the “hh” (hours) value. Saving the file back again will result in corrupted time data and KinAiry will object. If you do open a *.csv file with Excel, you can overcome this challenge by reformatting the time column as hh:mm:ss rather than accepting Excel’s default format interpretation.

APPENDIX C: HOW TO EXPORT DATA POINTS FROM METROLOG X4

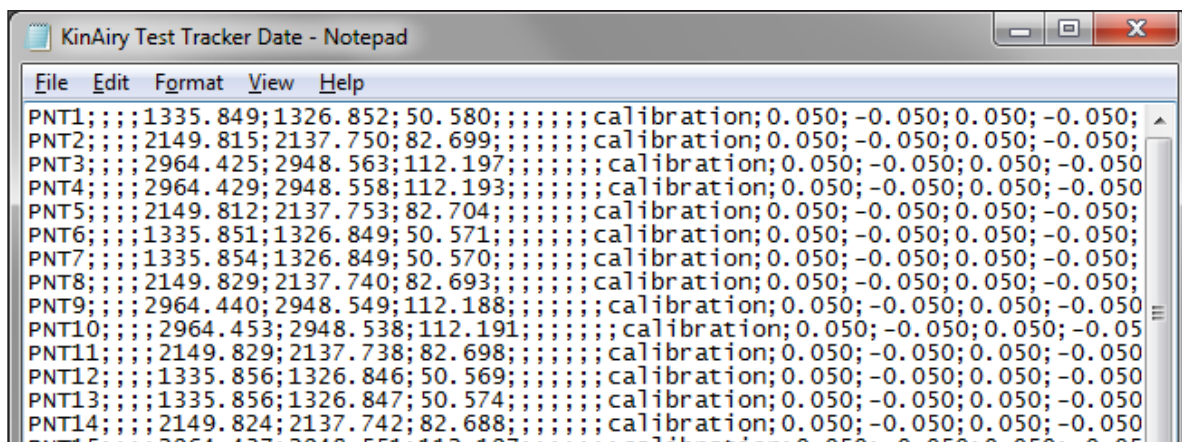
To prepare a text file for export to KinAiry using Metrolog, begin by taking the points in the same order as presented in KinAiry Guided Walkthrough mode.



From the menu, select **Working Session, Export**. In the Export Results dialog, choose **ASCII RAW DATA (*.txt)** as the Format. Click **OK**, name the data file, and save it in a location convenient to access later from KinAiry.

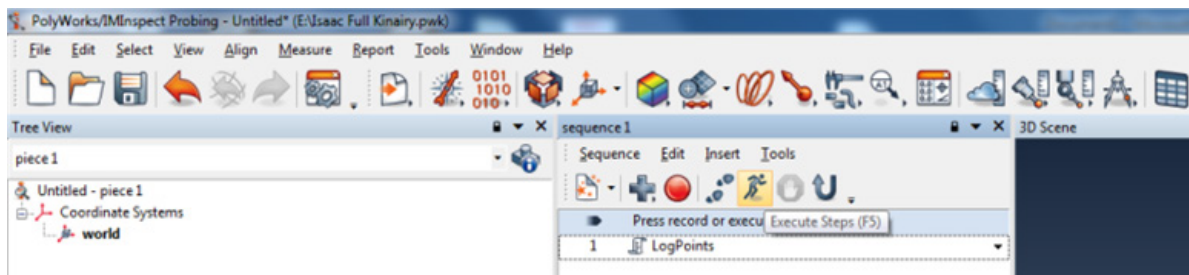
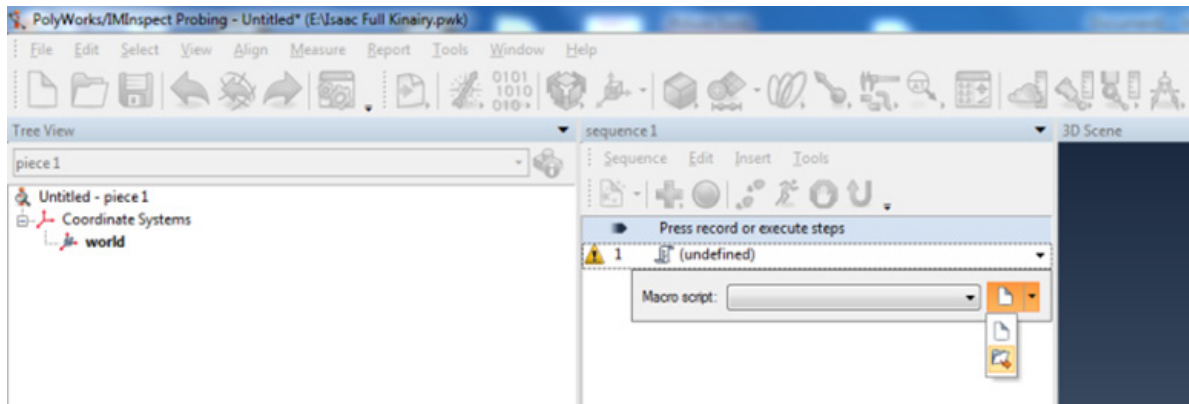


Import the text data file using KinAiry software, **Import Data File** function.



APPENDIX D: HOW TO EXPORT DATA POINTS FROM POLYWORKS

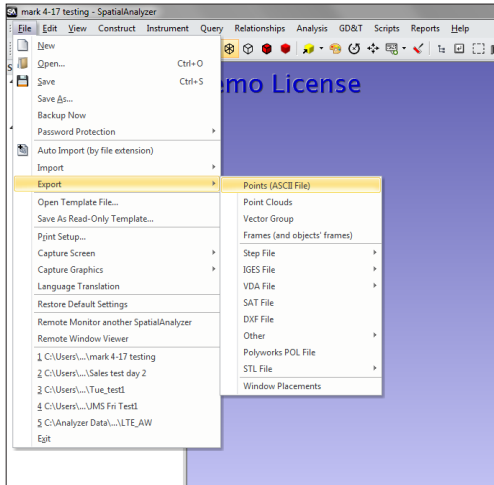
A macro script is utilized to export/log points during KinAiry calibration and testing. To begin, download the KinAiry LogPoints macro available on the Polyworks website. Begin the KinAiry test using the Guided Walkthrough option. After bucking-in the tracker, but before taking points, start the custom macro.



The macro will prompt the user to select a folder location and enter a filename. It will then collect and sequentially log point data in a text file. The macro does not assist with the KinAiry test or allow for custom naming of each point or point set. It is important for the user to take the points in the same order as presented in the KinAiry Guided Walkthrough. Do not stop the macro until the test is complete; only use the **Execute Steps**, **Take Point**, **Home**, and **Change Face** buttons. After completing the test the macro can be stopped. The text file will be ready to import into KinAiry with no further editing.

Import the text data file using KinAiry software, **Import Data File** function.

APPENDIX E: HOW TO EXPORT DATA POINTS FROM SPATIAL ANALYZER®

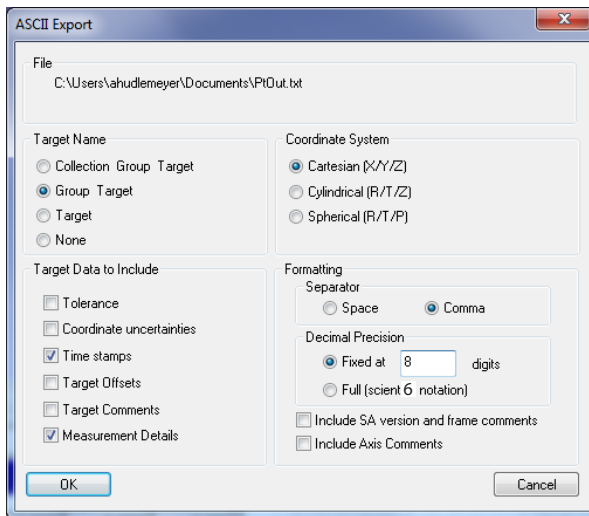


KinAiry is capable of automating SpatialAnalyzer to collect points, but if you have already used SA to complete an interim field test, you can still import an SA point file using the steps below.

To prepare a text file for export to KinAiry using SpatialAnalyzer®, begin by taking the points in the same order as presented in KinAiry Guided Walkthrough mode. From the menu, select **File, Export, Points (ASCII File)**.

SA will then prompt you to select points. Press **F2** and check the boxes corresponding to the data points.

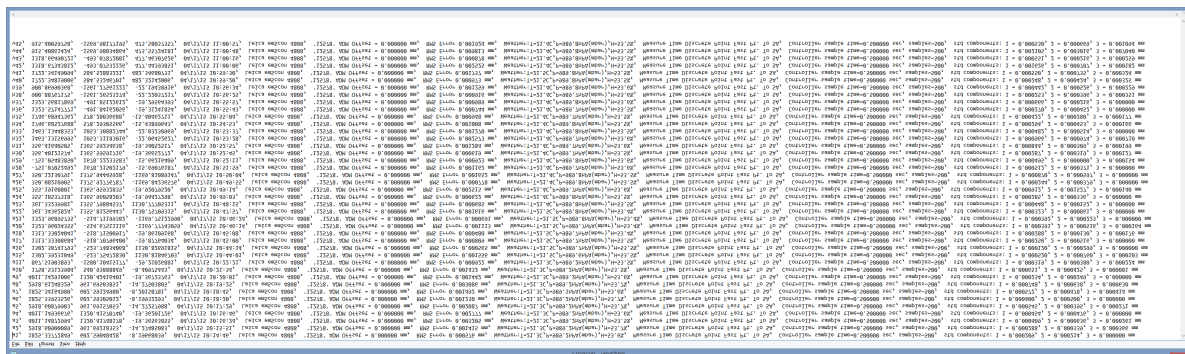
Once selected, SA will prompt for a file name and location to save the points. Save the text file in a location convenient to access from KinAiry software.



After clicking **Save**, SA will open a dialog with **Options** for what data to be exported.

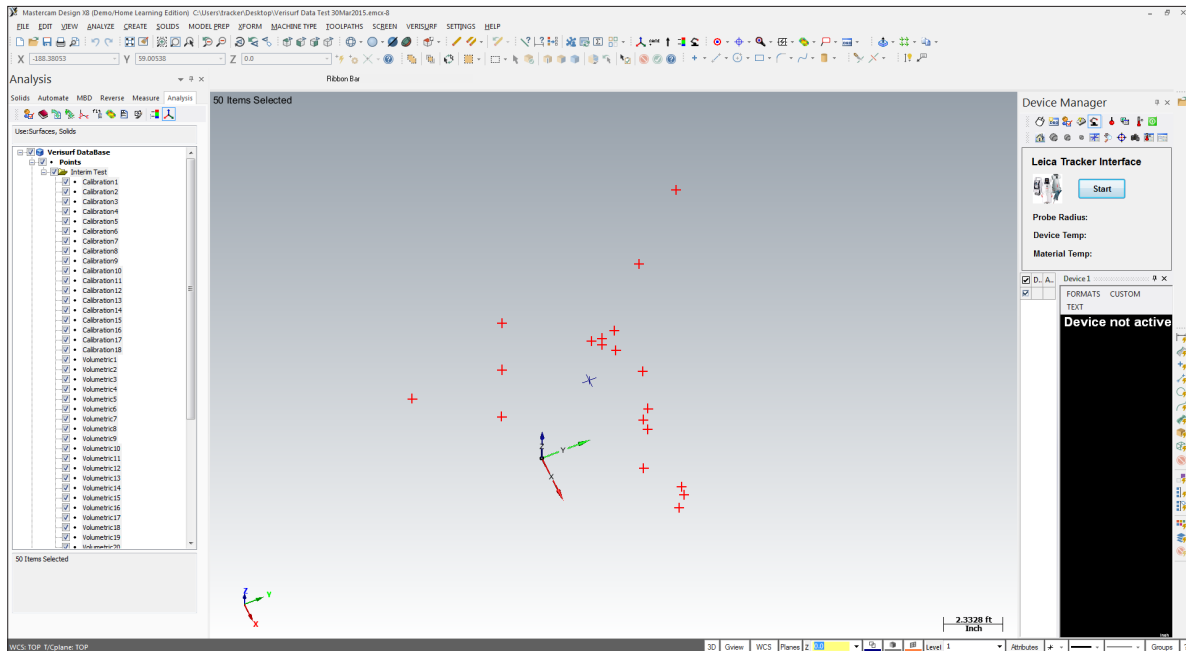
For **Target Name**, any option may be selected. The names are ignored because the point data is assumed to be in a known order. Select the **Cartesian (X/Y/Z)** coordinate system. For **Target Data to Include**, select **Time stamps** and **Measurement Details**. Under **Formatting**, choose **Comma** as the separator. **Decimal Precision** defaults at 6, which is sufficient in either millimeters or inches. Do not include **SA version** or **Axis Comments**. Click **OK** to complete the export.

The text file will contain many columns of data. Close the text file and import it using KinAiry software, **Import Data** File function.



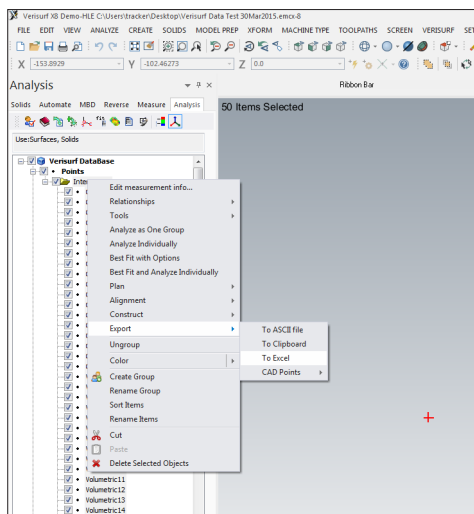
APPENDIX F: HOW TO EXPORT DATA POINTS FROM VERISURF X8

To prepare a data file for export to KinAiry using Verisurf X8, begin by taking the points in the same order as presented in KinAiry *Guided Walkthrough* mode. Once recorded, select the points for export by checking the appropriate boxes in the feature tree on the left-hand side.



Right-click on one of the points, and select Export, To Excel. Save the XLS file in a location convenient to access from KinAiry software.

The Verisurf XLS file will contain many columns of information for each data point. Close the file and import it using KinAiry software, **Import Data File** function.



The screenshot shows the Excel spreadsheet with the exported data from Verisurf X8. The spreadsheet contains columns for Name, X, Y, Z, and Time. The data is organized into rows for Calibration and Volumetric measurements.

	A	B	C	D	E	F	G	H
	Name	X	Y	Z				Time
1								
2	Calibration1	-50.0054	53.3026	-3.0251	6836	-7287	0414	Mon Mar 30 13:23:36 2015
3	Calibration2	-80.9592	86.3094	-4.8552	6836	-7287	0410	Mon Mar 30 13:23:52 2015
4	Calibration3	-111.8939	119.2952	-6.6672	6836	-7288	0407	Mon Mar 30 13:24:04 2015
5	Calibration4	-111.8940	119.2951	-6.6673	6836	-7288	0407	Mon Mar 30 13:24:12 2015
6	Calibration5	-80.9590	86.3097	-4.8553	6836	-7287	0410	Mon Mar 30 13:24:25 2015
7	Calibration6	-50.0054	53.3024	-3.0252	6836	-7287	0414	Mon Mar 30 13:24:41 2015
8	Calibration7	-50.0054	53.3025	-3.0253	6836	-7287	0414	Mon Mar 30 13:24:53 2015
9	Calibration8	-80.9589	86.3097	-4.8553	6836	-7287	0410	Mon Mar 30 13:25:06 2015
10	Calibration9	-111.8936	119.2954	-6.6673	6835	-7288	0407	Mon Mar 30 13:25:18 2015
11	Calibration10	-111.8937	119.2954	-6.6673	6836	-7288	0407	Mon Mar 30 13:25:26 2015
12	Calibration11	-80.9590	86.3096	-4.8553	6836	-7287	0410	Mon Mar 30 13:25:40 2015
13	Calibration12	-50.0054	53.3024	-3.0252	6836	-7287	0414	Mon Mar 30 13:25:55 2015
14	Calibration13	-50.0054	53.3023	-3.0252	6836	-7287	0414	Mon Mar 30 13:26:06 2015
15	Calibration14	-80.9589	86.3098	-4.8557	6836	-7287	0410	Mon Mar 30 13:26:19 2015
16	Calibration15	-111.8937	119.2953	-6.6676	6836	-7288	0407	Mon Mar 30 13:26:30 2015
17	Calibration16	-111.8936	119.2954	-6.6676	6835	-7288	0407	Mon Mar 30 13:26:38 2015
18	Calibration17	-80.9589	86.3097	-4.8554	6836	-7287	0410	Mon Mar 30 13:26:52 2015
19	Calibration18	-50.0054	53.3024	-3.0253	6836	-7287	0414	Mon Mar 30 13:27:20 2015
20	Volumetric1	-46.6618	51.9045	-2.9317	6680	-7430	0420	Mon Mar 30 13:28:10 2015
21	Volumetric2	43.8515	54.1771	-2.3128	-6288	-7765	0332	Mon Mar 30 13:28:28 2015
22	Volumetric3	-1.8919	52.5748	42.6211	0280	-7765	6295	Mon Mar 30 13:28:58 2015
23	Volumetric4	-1.8983	52.5743	42.6236	0280	-7765	6295	Mon Mar 30 13:30:11 2015
24	Volumetric5	-1.3485	53.0429	-2.6579	0254	-9984	0500	Mon Mar 30 13:30:38 2015
25	Volumetric6	-1.3481	53.0429	-2.6571	0254	-9984	0500	Mon Mar 30 13:30:52 2015
26	Volumetric7	-7604	53.5104	-47.9098	0109	-7450	6670	Mon Mar 30 13:31:21 2015
27	Volumetric8	-7791	53.5113	-47.9088	0108	-7450	6670	Mon Mar 30 13:31:33 2015
28	Volumetric9	-52.5132	2.3152	42.6165	7761	-0342	-6296	Mon Mar 30 13:32:34 2015
29	Volumetric10	-52.5388	2.3149	42.6170	7761	-0342	-6297	Mon Mar 30 13:32:43 2015
30	Volumetric11	-52.9483	2.9074	-2.6647	9972	-0548	0502	Mon Mar 30 13:33:12 2015
31	Volumetric12	-52.9483	2.9079	-2.6638	9972	-0548	0502	Mon Mar 30 13:33:20 2015

APPENDIX G: EXPLANATION OF THE CALIBRATION PROCESS

This KinAiry length artifact does not ship with a calibrated length certificate. The calibrated length is meant to be set in the field using the ranging system of the laser tracker. This procedure is relevant when the distance ranging performance of the laser tracker (i.e., straight IFM or straight ADM) is significantly more accurate than the angle measurement performance for volumetric checks, and is detailed in ASME B89.4.19^[3].

When taking calibration and measurement data, special care should be taken to obtain accurate readings:

- The length artifact must be allowed to soak in the environment to reach temperature equilibrium.
- To achieve the smallest uncertainties, counterweights are required to compensate for compliance of the stand and the support structure under the load of a retroreflector. On the length artifact are found three pairs of two target nests. Each pair is labeled A, B, or C. The nests on the face of the length artifact hold a retroreflector while taking calibration and measurement data. The nests on the top of the length artifact hold a counterweight when a retroreflector is not present in that position. For example, if a retroreflector has been placed in target nest C to take a measurement, counterweights will be placed in the other two locations (on the top of the length artifact, in nests A and B). As the retroreflector is moved from one target nest to the other, the counterweights are shifted into the empty positions prior to taking the measurement.
- At least when taking the calibration shots, the same retroreflector should be used in all three measurement locations A, B, and C in order to eliminate depth errors. Additionally, to eliminate runout error of the retroreflector, it should be placed in each nest in the same orientation. Use the engraving on the body of the retroreflector, or other indicator on the bezel to maintain a consistent orientation.
- Alternatively, after the calibration phase (during the point measurement phase), the length artifact can be loaded with three high-precision retroreflectors, in each of the target nests on the face of the artifact. The tracker can then be directed to each target by use of a measurement plan.

Pre-Calibration Alignment

The KinAiry system comes equipped with a folding mirror to simplify the alignment procedure. The weight of the mirror is balanced with a built-in counterweight on the opposite end of the artifact. The calibrated length will be set while the detachable mirror is in place. It must remain in place throughout the interim test to maintain the calibrated length even though it is not actually used after calibration. To realize the accuracy of the in-line range performance of the laser tracker, the target nests of the scale bar must be aligned within 0.1 degrees azimuth and elevation, as seen from the laser tracker.

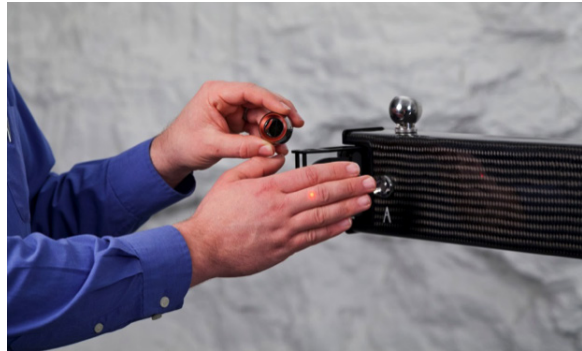
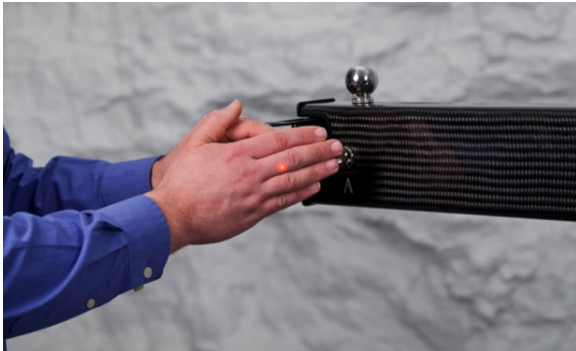
When automating the test with KinAiry's "Create SA Interface" mode, you will be guided through this process, with calculations indicating success. But if not, you'll need to know the following.

Note that it is not necessary to reposition the counterweights (as described above) during the pre-calibration alignment process.

- Set up KinAiry hardware components and your tracker in preparation for the test as described in Chapter 1: Getting Started.
- Remove the retroreflector from home position on the laser tracker.



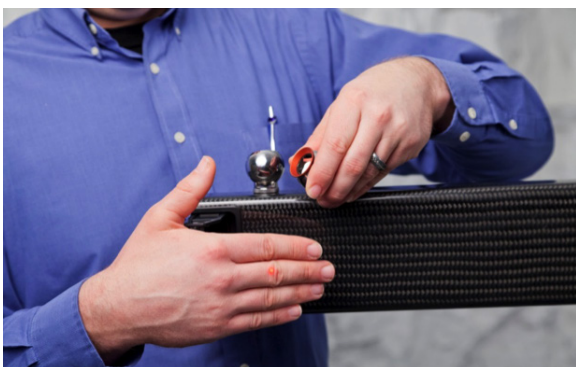
Place the retroreflector in front of the mirror so that the tracker beam path is aimed at the center of the mirror.



Break the beam path and remove the retroreflector to end tracking. The laser beam should now reflect off of the mirror.



Place the retroreflector near target A in the path of the reflected beam, and allow the tracker to re-acquire the retroreflector. Once the tracker locks on, place the target in target nest A.



At this point, the beam is reflected off the mirror and directly into the retroreflector sitting in target nest A. Break the beam again, and then remove the retroreflector from target nest A.



Place the retroreflector in target nest C. The laser tracker will most likely not be pointing at the center of the retroreflector in this position.

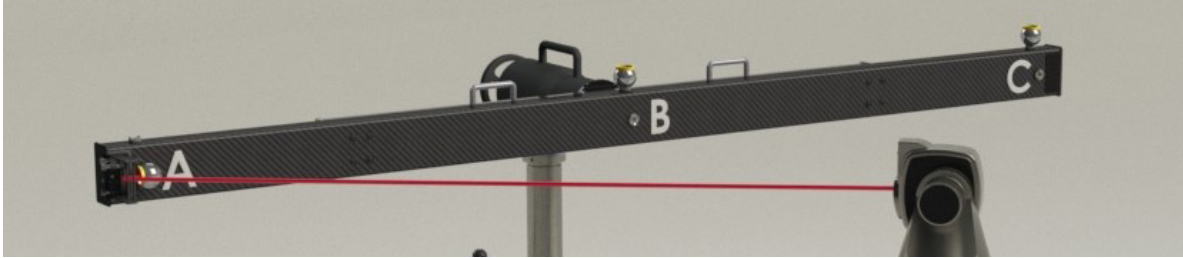


Manipulate the tip-tilt adjustments on the mirror mount to direct the beam path into the center of the retroreflector in target nest C. Make sure the tracker re-acquires the target.

- Set the tracker software to show live data for horizontal and vertical (azimuth and elevation) angles. Please note that you may have to change your display from a Cartesian coordinate system (x, y, z) to a spherical coordinate system (r, θ, ϕ).
- Note both angles while the laser tracker is aiming at the retroreflector in target nest C.
- Carefully remove the retroreflector from target nest C, and place it in target nest A. Note the horizontal and vertical angles again.
- Calculate the difference in horizontal angles from nest C to nest A as well as the difference in vertical angles from nest C to nest A. If both differences are less than 0.1 degrees, sufficient alignment has been achieved. If not, iterate through the procedure one more time. For the interim field test geometry, no more than 2 iterations should be required.

Taking the Calibration Measurements

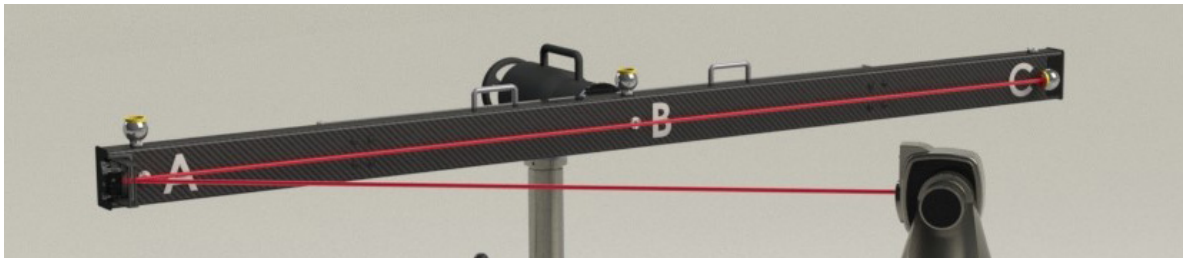
After the pre-calibration alignment is complete, the next task is to measure the lengths between the three target nests. These lengths will be assigned as the calibrated lengths, and compared against volumetric length measurements to obtain the measurement error values.



Measure Target A, Counterweight at Positions B and C



Measure Target B, Counterweight at Positions A and C



Measure Target C, Counterweight at Positions A and B

If you have chosen to take several calibration shot repetitions, the KinAiry procedural guidance will explain the shot order to be: A, B, C, C, B, A, A, B, C, etc. Note that the KinAiry software expects points to be recorded in this same sequence when importing data. The first calibration point group moves from A to B to C. After taking point data in target nest C, you should remove the retroreflector from nest C, and then reseal it directly back into nest C again, in preparation for the next point group from C to B to A. This process gives fully independent calibration sets. Similarly, when you get back to nest A, the retroreflector should be removed and reseated prior to heading back to B and C.

APPENDIX H: THE INTERIM TEST PROCEDURES

Standard tests of laser tracker performance have been developed (B89.4.19^[3], ISO 10360-10^[1], VDI/VDE 2617 Blatt 10^[4]). These tests use prescribed measurements under controlled laboratory conditions to determine or verify a laser tracker's performance characteristics, or to serve as a basis of common comparison between instruments. Manufacturer field checks or compensation routines are designed to isolate specific error modes, but are not as comprehensive as the standard tests^[5]. The role of interim testing is to evaluate instrument performance and errors under the same conditions as the measurement job, and answer the question, "How is my tracker performing right now?" Results from interim testing can be used as part of a quality system to confirm instrument performance prior to critical and costly measurements, and to track instrument performance over time.

The interim field test is comprehensive in that it uses both two-face checks and length measurements to quantify volumetric laser tracker performance, following a calibration which is accomplished by isolating the ranging element of the tracker. The positions and orientations have been carefully selected and justified to be sensitive to known error parameters, but the test is sufficiently brief to be accomplished in less than 30 minutes. After calibration of the length artifact has been established, the NIST Interim Field Test calls for length measurements and two-face checks in several orientations.

The following checks can be done in one of two ways. The target points can be measured using a single retroreflector, which will require counterweighting the beam and much handling of the retroreflector and artifact. This approach can be beneficial if very accurate target reflectors are not available, by reducing the error contribution from depth and runout from a single target. Alternatively, the artifact can be loaded with three high-precision retroreflectors, one in each of the target nests. The tracker would be directed to each target by use of a measurement plan. The advantage of this method is reduced time and handling of the system. For each setup, the azimuth of the tracker body, and the orientation of the artifact are specified. Front and back face measurements are taken for each point, A, B, C, in each orientation.

The following tables illustrate the ISO (Table 1) and NIST (Table 2) interim field testing procedures.

Table 1. ISO/ASME Interim Field Test orientations.

Position	Artifact Orientation	Tracker Azimuth
1	Elevated	0 °
2	Horizontal 0	0 °
3	Horizontal 90	90 °
4	Vertical 90	90 °
5	Vertical, User-defined Distance	Different from position #4 (KinAiry requires moving at least $\pm 45^\circ$ away from Position 4 azimuth)

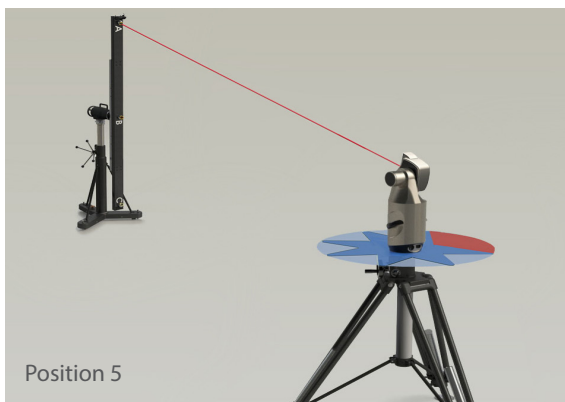
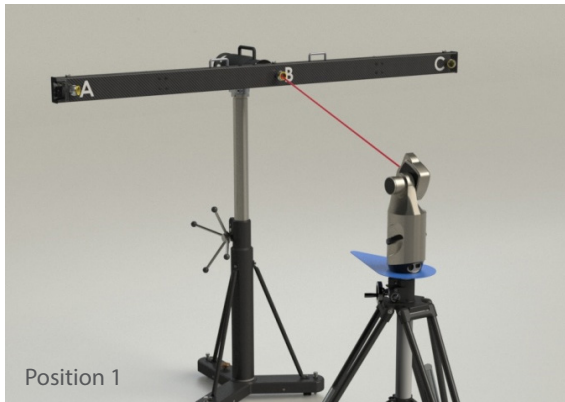


Table 2. IR-8016 Interim Field Test orientations.

Position	Artifact Orientation	Tracker Azimuth
1	Vertical	0 °
2	Vertical	90 °
3	Horizontal	90 °
4	Horizontal	0 °
5	Horizontal with 0.5m vertical offset	0 °



When running the NIST IR-8016, there is an additional R0 check for IFM trackers with a birdbath. KinAiry software will prompt an additional measurement step if a laser tracker is selected which operates in ADM and IFM mode. Further detail is available in the documentation for the NIST Interim Field Test ^[5].

Results

Once all measurement points are complete and recorded, measurement errors can be calculated. For two-face errors, the error is taken as the distance between the front and back-face measurement points for each target and test position. For length measurements, the error is taken as the difference between the measured lengths in front face only and the calibrated lengths.

The error values summarize the volumetric measurement performance of the laser tracker. They describe the measurement error of the tracker in the conditions which it's operating, and can be compared against other results taken over time, results taken at the time the tracker is factory calibrated, error limits for an internal quality system, or published MPEs.

Traceability

The interim field test relies upon measurements of points and calculated distances between points. Traceability of those measurements can be maintained following guidance from standards like: ASME B89.7.5, JCGM 200:2012, or ILAC P10:01/2013. It is important to note that the documentation of traceability to a metrological terminus is intended to come from the calibration of the laser tracker range system used to establish the reference length.

APPENDIX I: THE UNCERTAINTY BUDGET

Uncertainty Budget Components

Below are the uncertainty budget components for the calibration and measurement of the artifact used in the interim field test under field conditions.

The reference lengths found below (2.3m and 1.15m) are defined as the distances between the centers of any two target nests on the face of the length artifact. Components of uncertainty in the reference lengths are described below.

Table 2. Uncertainty Budget for the Calibrated Length of the Artifact

Component	Symbol	1 Standard Uncertainty (μm)	
		2.3m	1.15m
Optical Alignment, Interferometer and Angular Encoders	L_{tracker}	0.6	0.4
Repeatability of Nests	L_{repeat}	1.5	1.5
Gravity Loading	L_{gravity}	2.5	1.6
Retroreflector	L_{retro}	1.4	1.4
Artifact Temperature	L_{temp}	2.2	1.1
	$U_{k=2}$	7.9	5.7

L_{tracker}

This component of uncertainty describes the effectiveness of the laser tracker in measuring the distance between points. There are three components to consider, the accuracy of the ranging component, the performance of the angular encoders, and the optical alignment. The mirror used in the alignment is flat to $\lambda/10$ and is considered negligible. For one target reflector used in the same orientation in all nests during calibration, the depth and runout errors do not contribute to alignment errors. If the optical alignment is contained within 0.1 degrees, the projected error due to the transverse error of the tracker is also negligible. The laser tracker used in this example analysis reported a maximum permissible error (MPE) of the ranging component accuracy of $\text{MPE}_{\text{range}} = \pm 0.4\mu\text{m} + 0.3\mu\text{m}/\text{m} \cdot L$. For the 2.3m length, $\text{MPE}_{\text{range}} = \pm 1.1\mu\text{m}$. Converting from a rectangular distribution to a normal distribution gives $L_{\text{tracker}}(1\sigma) = 0.6\mu\text{m}$.

L_{repeat}

As a target reflector is repeatedly placed in a target nest on the artifact, variability can be observed. This variability can come from form of the sphere or nests, the support structure, or other physical behavior, as well as variability of the laser tracker discussed above. Because the targets will be placed in the nests differently during the volumetric portion of the test, and because this error would create systematic errors in the measurement, it is conservatively treated as being independent from variability in the tracker. Repeatability was tested during laboratory testing at NIST, and determined to be $L_{\text{repeat}} (1\sigma) = 1.5\mu\text{m}$.

L_{gravity}

The length of the artifact changes slightly due to gravity loading as the artifact is oriented horizontal or vertical. Careful design has minimized this effect, and the conformance limit is $L_{\text{gravity}} (1\sigma) = 2.5\mu\text{m}$ for the 2.3m length. Assuming a uniform distribution gives $L_{\text{gravity}} (1\sigma) = 1.7\mu\text{m}$. This error component is controlled as part of the overall manufacturing quality system.

L_{retro}

The target reflectors used for this uncertainty budget had a MPE of $2.5\mu\text{m}$ between the optical and mechanical centers. For random projection along the length measurement axis, $L_{\text{retro}} (1\sigma) = 1.4\mu\text{m}$.

L_{temp}

Uncertainty due to temperature has two components, variation of the temperature of the artifact and uncertainty of the coefficient of thermal expansion of the artifact. Presuming the artifact has soaked in the environment for sufficient time to approach equilibrium, a reasonable boundary is set at a maximum temperature variation of the artifact of 1°C . The coefficient of thermal expansion of the carbon tube is $1.5 \times 10^{-6} / ^\circ\text{C}$. The standard uncertainty for the 2.3m length due to temperature variation is $2.0\mu\text{m}$. The uncertainty of the coefficient of thermal expansion is conservatively estimated to be a uniform distribution up to 50% of its nominal value, $0.75 \times 10^{-6} / ^\circ\text{C}$, which gives a standard uncertainty of $1.0\mu\text{m}$. Combining these two components, $L_{\text{temp}} (1\sigma) = 2.2\mu\text{m}$.

$L_{\text{stability}}$

Testing at NIST was conducted to determine uncertainty in the length due to dimensional stability of the artifact over the time allowed to conduct the interim test (60 minutes). Dimensional stability was found to be insignificant over this brief time period.

Summary

Several contributing factors were analyzed to determine a combined expanded uncertainty for the artifact during an interim test: alignment and performance of the tracker when calibrating the reference length, repeatability of seating a retroreflector in a target nest, gravity loading of the artifact in varying orientations, target reflectors used in the length measurement tests, and temperature effects. This uncertainty is based on validity conditions appropriate to field use:

- The artifact has soaked in the environment and will not vary in temperature more than $\pm 1^{\circ}\text{C}$ from the temperature at time of calibration.
- The artifact is calibrated in the horizontal orientation only.
- The test is to be conducted within 1 hour.

WARRANTY

All goods are sold by Brunson Instrument Company without any implied warranties of merchantability or fitness for use and without any other warranties, expressed or implied, except as set forth below.

Any goods manufactured by Brunson Instrument Company, and found by Brunson Instrument Company, to be defective in material or workmanship will be repaired, or at Brunson Instrument Company's option, replaced, for the original purchaser only, provided the goods are returned with authorization to and by Brunson Instrument Company, transportation prepaid, within one year of the original shipment from Brunson Instrument Company. This warranty does not apply to goods, which have been subjected to alteration or servicing, rough handling, misuse, negligent use, fire damage, water damage, or other casualty or to ordinary wear and tear.

Repair or replacement of the defective products, as provided above, is the sole remedy of the purchaser of products covered by this warranty and is the complete statement of Brunson Instrument Company's liability with respect to such products. Brunson Instrument Company shall have no other or further liability with respect to such products, whether in tort, negligence, contract, theory of strict tort liability or other theory.

Limited lifetime warranty for horizontal and vertical axis ball bearings: trunnion and spindle bearings manufactured by Brunson Instrument Company, and found by Brunson Instrument Company to be defective in material or workmanship, will be repaired or replaced at Brunson Instrument Company's option for the original purchaser only, provided the instrument for which the bearings were returned, with authorization to and by Brunson Instrument Company, transportation prepaid with documentation to support that the instrument has been fully serviced by an authorized Brunson Instrument Company service representative at least at a minimum of three – and a maximum of five – year intervals from the date of original shipment at the time of purchase from Brunson Instrument Company, and the instrument has not been subjected to alteration, rough handling, misuse, negligent use, fire damage, water damage or any other casualty.

The repair or replacement of the defective products, as provided above, is the sole remedy of the purchaser of products covered by this warranty as the complete statement of Brunson Instrument Company's liability with respect to such products. Brunson Instrument Company shall have no other or further liability with respect to such products, whether in tort, negligence, contract, theory of strict tort liability, or other theory.

REFERENCES

- [1] ISO, ISO/DIS 10360-10:2021: Geometrical product specifications (GPS)-acceptance and reverification tests of coordinate measuring systems (CMS): part 10. Laser trackers for measuring point-to-point distances, Geneva: International Standards Organization, 2013.
- [2] ISO, ISO/TC 14253-1:2013 Geometrical product specifications (GPS) -- Inspection by measurement of workpieces and measuring equipment -- Part 1: Decision rules for proving conformity or nonconformity with specifications, Geneva: International Standards Organization, 2013.
- [3] ASME, B89.4.19-2021: Performance Evaluation of Laser-Based Spherical Coordinate Measurement Systems, New York: American Society of Mechanical Engineers, 2006.
- [4] VDI, VDI/VDE 2617 Blatt 10: Accuracy of Coordinate Measuring Machines Characteristics and their Checking Acceptance and Reverification Tests of Laser Trackers, Berlin: Verein Deutscher Ingenieure, 2011.
- [5] V. Lee, C. Blackburn, B. B. S. Muralikrishnan, D. Sawyer, M. Meuret and A. Hudlemeyer, A Proposed Interim Check for Field Testing a Laser Tracker's 3-D Length Measurement Capability Using a Calibrated Scale Bar as a Reference Artifact, <http://dx.doi.org/10.6028/NIST.IR.8016>.



Brunson Instrument Company

8000 E 23rd Street
Kansas City, MO 64129

www.brunson.us
info@brunson.us

Tel (816) 483-3187

Fax (816) 241-1945

© Copyright 2023 Brunson Instrument Company