MeasureDirect Users Guide

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Purpose

The *MeasureDirect* utility is inspection software with a very narrow scope of capability focusing on the measurement of artifacts for CMM calibration. *MeasureDirect* can perform measurement tests using a step gauge, gauge block, ring gauge, pin gauge, sphere, B89.4.1 or 10360 ball bar, and laser.

The inspiration behind the development of this utility is to solve the problems of program incompatibility when working on different brands of CMM's. The *MeasureDirect* utility is intended to reduce the reliance on part programs for the various inspection softwares that exist. Writing inspection software to help solve the problem with part program compatibility is really over the top but this approach has a number of benefits and offers capability for future projects.

MeasureDirect doesn't use an external part program scripting language but the capability for this may be added in the future. The scripting language would allow customization of the measurement routines at a minimum.

User Interface

The user interface of *MeasureDirect* is shown in illustration 1. The various options are grouped into sections where each section handles one aspect of the utility.

Table 1: MeasureDirect sections:

Section	*Description*
CMM	Configuration and connection to the controller and related functions.
Settings	Options specific for the machine and artifacts.
Tools	Configuration and calibration of tools.
Measure	Various measurement tests that can be performed.
Output, Reporting, and Validation	Configuration for the output of measurement data, access to the *MeasureView* utility, and ability to generate test data for best fit feature validation.

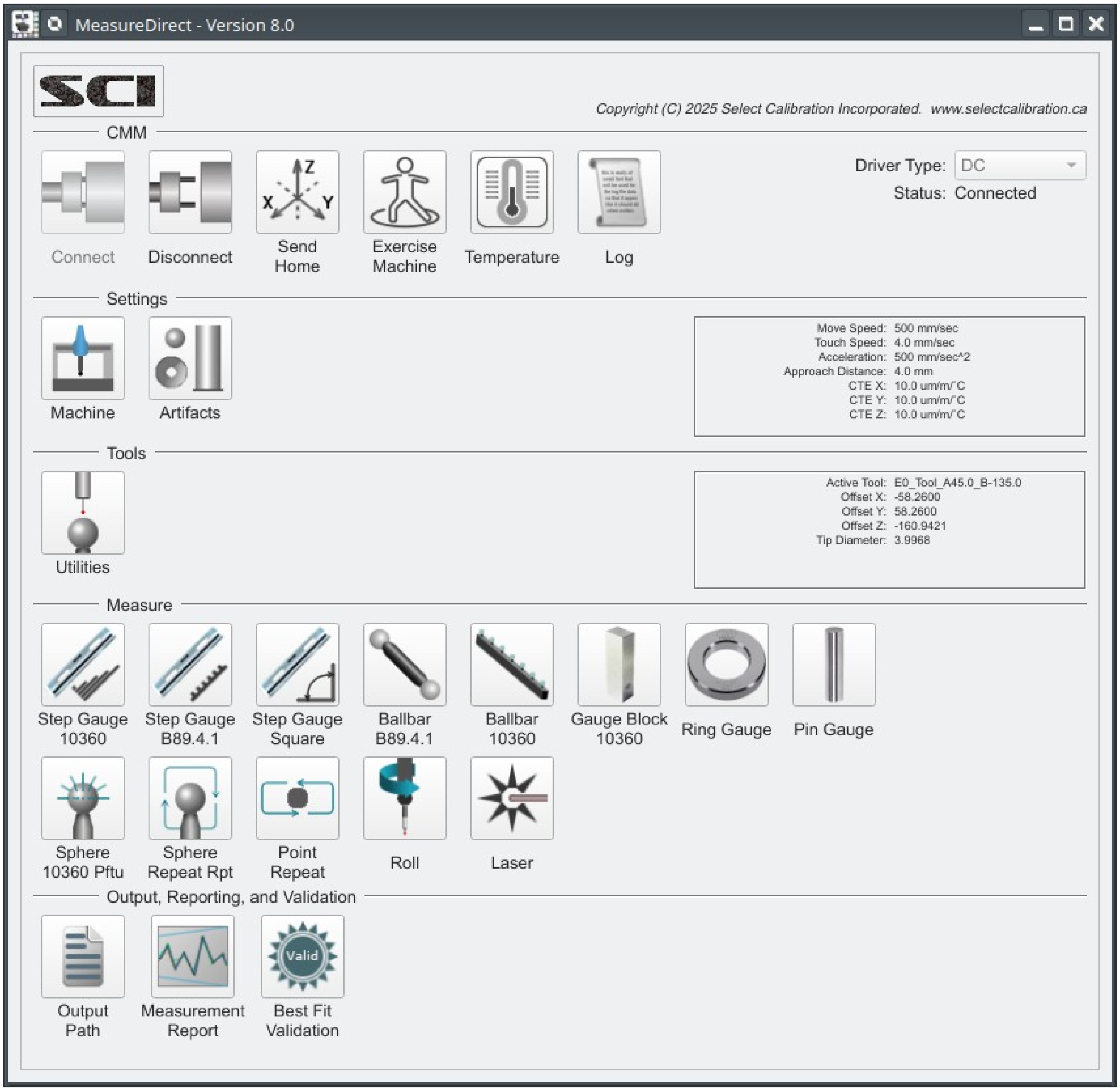


Illustration 1: Main screen of the MeasureDirect utility.

CMM

The CMM section handles the interface to the machine and supports a limited number of driver types for CMM controllers.

Table 2: CMM Options

Option	*Description*
Connect	Connect to the CMM controller specified by the *Driver Type* selection.
Disconnect	Disconnect from the CMM controller.

Option	*Description*
Send Home	Send the machine home.
Exercise Machine	Perform a sequence of moves in a loop to warmup the machine.
Temperature	Show information for all machine temperature sensors.
Log	Display a window showing messages to or from the CMM controller.
Driver Type	Driver to be used to connect to a specific kind of CMM controller.

Driver Type

The driver type represents an implementation of the protocols necessary to talk to a CMM controller. The *MeasureDirect* utility can support a number of different drivers. The driver type refers to the protocol where the controller type is the physical CMM controller and it is possible to have a physical controller that can support more than one communication protocol.

The CMM controller must handle the geometric compensation in order to be used by *MeasureDirect*. It is possible to add geometric compensation to the *MeasureDirect* utility but a problem arises where the interpretation of the map data may be different between *MeasureDirect* and the native CMM software so, primarily for this reason, configurations of controllers that do not handle the geometric compensation are not supported.

Table 3: Driver Types:

Name	*Description*
I++ Client	Connect to an I++ server. This is the typical driver used when dealing with Renishaw systems.
Leitz	Connect to a Hexagon common controller configured for Leitz protocol. This controller was used from roughly 2000 to 2014.
DC	Connect to a DC controller. This controller was used from approximately 2012 to present.
Virtual CMM	Connect to a Virtual CMM. This is a separate utility developed by SCI that simulates a coordinate measuring machine.

Starting with version 6.0 of MeasureDirect the Simulation driver was removed. Use VirtualCMM if a simulated controller is needed.

Exercise Machine

The exercise machine function allows the user run the machine through a pre-defined pattern of moves. The moves are inside the cube defined by the two extreme corners as shown in the *Exercise Machine* dialog.

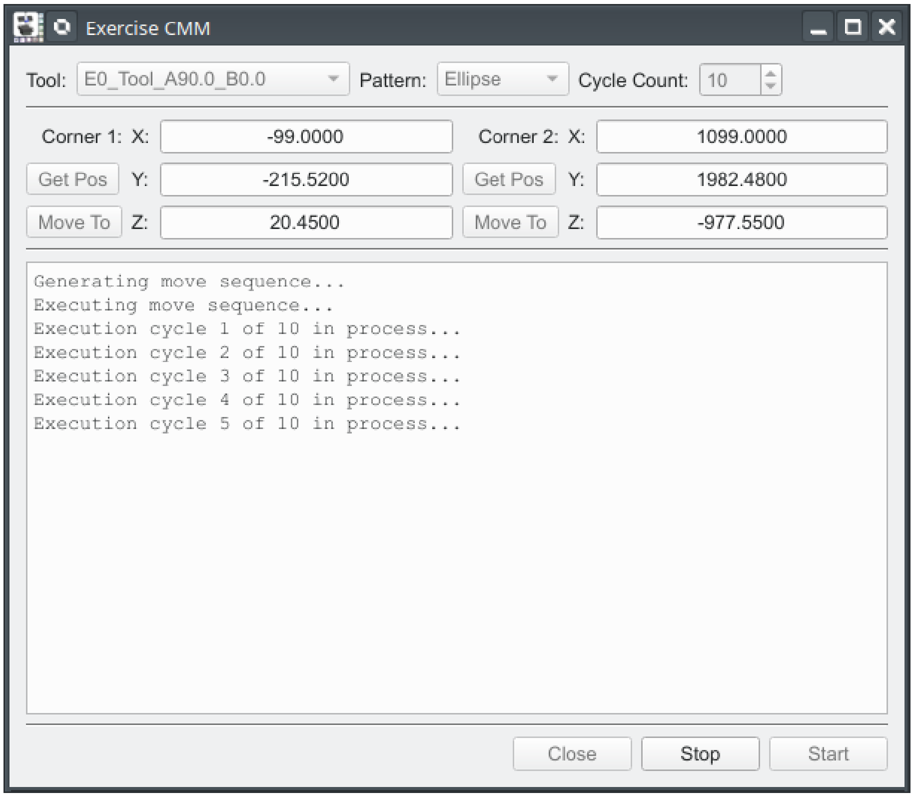


Illustration 2: Exercise machine dialog.

Table 4: Exercise Machine Options:

Option	*Description*
Tool	Selection of the active tool.
Pattern	Pattern of moves for each measurement cycle. See *Move Pattern* for details.
Cycle Count	Total number of times to run the pattern.
Get Pos	Get the current position of the machine and update the associated XYZ corner.
Move To	Drive the CMM to the specified XYZ coordinate.
Close	Close the exercise dialog. If a sequence is currently running it is stopped.
Stop	Stop the active sequence.
Start	Start the execution of the sequence.

When running the exercise cycle the controller command buffer is disabled (set to a size of one command). This will disable controller features such as blended moves and it also forces the machine to stop at each target position. It is unknown which version puts more stress on the machine but it is believed the constant stopping and starting is more stressful then a fluid move along a pre-calculated path. From an aesthetic point of view the blended move version will look better and run faster but this is not the goal of this function.

Starting with version 6.0 of MeasureDirect the two corners can be the extreme edges of the machine volume. The volume used for the moves is reduce by 10 mm from the volume based on the two corner points.

Move Pattern

The different patterns that can be used to exercise the CMM can be one of the following options:

Table 5: Move Pattern Options:

Option	*Description*
Simple	The machine moves in a straight line between the two corners.
Ellipse	The machine moves in an elliptical pattern. The long axis of the ellipse in inline with the two corners.
Star Burst	The machine moves in an elliptical pattern with additional moves to the center position.
Zigzag	The machine moves in a zigzag pattern between the two corners.

Temperature Monitor

The temperature monitor utility shows the temperature for each axis, each axis sensor, and the part. Illustration 3 shows an example of the temperature monitor utility.

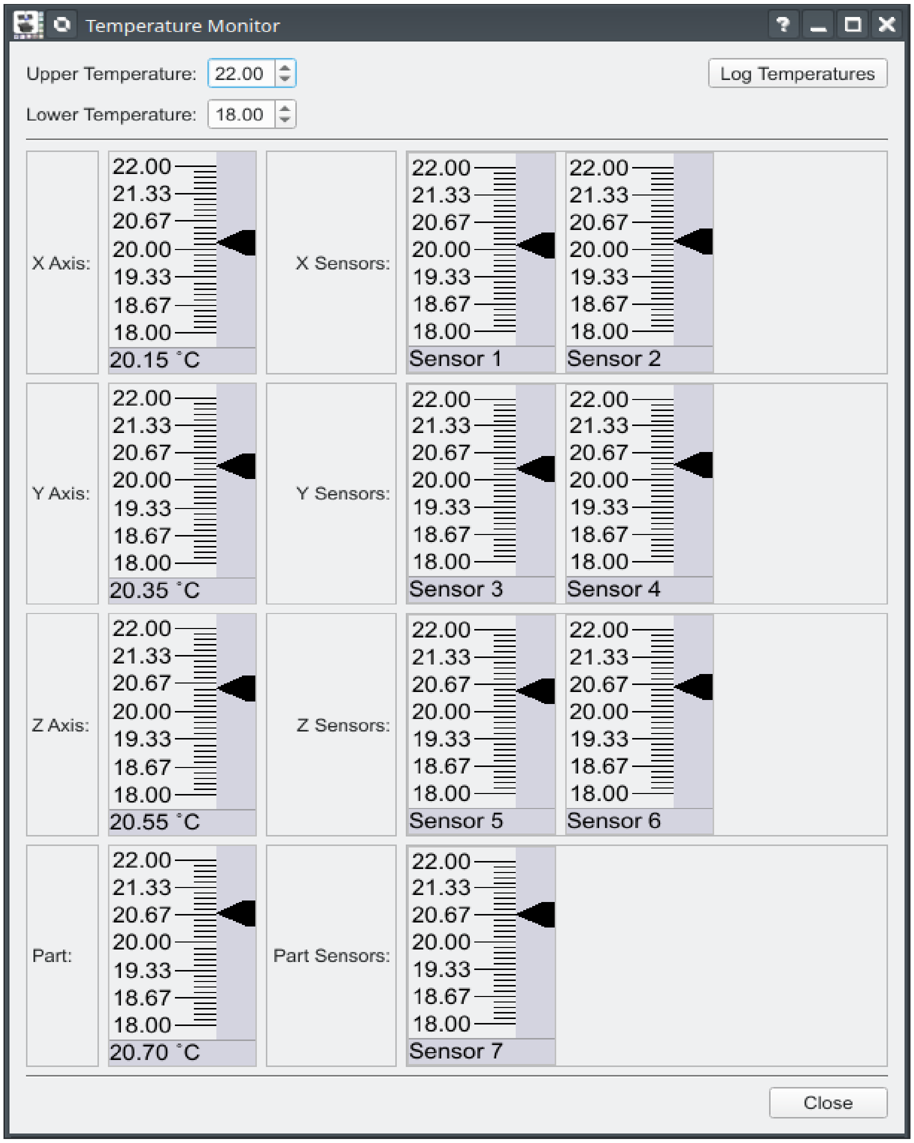


Illustration 3: Temperature monitor utility.

The temperatures are only updated when the utility is visible or when the temperature log is active. The range limits can be set as desired. Sensors are updated once every 40 seconds staggered between all axis and the part so that each update is at a 10 second interval. Temperatures beyond the temperature limits will be shown with a positive or negative out of range indicator.

The temperature log option will create a data file called *Temperature_Log [xxxx].Dat* where xxxx is replaced with the current date. The log files have a resolution of one day. The contents of the temperature log file can be displayed using *MeasureView*.

Table 6: Temperature Monitor Options:

Option	*Comment*
Upper Temperature	Upper temperature limit of the individual graphs.
Lower Temperature	Lower temperature limit of the individual graphs.
Log Temperatures	Creates a log file containing data from the machine temperature sensors.

Note: The temperature used for temperature compensation and the temperatures displayed by the temperature monitor function are independent. The temperature used for temperature compensation is updated at the start of the sequence and does not change during the measurement where the temperature monitor utility updates groups of sensors every 10 seconds continueously.

Note: The utility can remain open during measurement sequences in order to monitor changes in temperature.

Temperature Log File Format

The format of the temperature log file following the file header is a single line for each sampled temperature measurement. Each line consists of the time, an integer value identifying the sensor number, and the actual temperature. To keep the file size small the time is condensed into a six digit number with the format of [hhmmss]. A partial example of a temperature log file is shown below:

```
Temperature_Log:Version=1:Type=Machine_Sensors

# [hhmmss],<sensor_id>,<temperature>

[125715],1,19.46
[125755],1,19.24
[125845],1,19.15
[125915],1,19.11
[125955],1,19.11
[130054],1,19.24
[130115],1,19.35
[130155],1,19.46
[130240],1,19.67
[130315],1,20.01
[130355],1,20.26
...
```

The temperature log file records only the raw sensor data and not the resulting axis temperatures. The axis temperature will be the average of all the sensors assigned to it at any epoch of the data.

Settings

The settings section handles machine and artifact settings. Machine settings are specific to the CMM where artifact settings are used by *MeasureDirect* when measuring the different types of supported gauges.

Machine

The machine settings contains entries for move speed, touch speed, acceleration, and approach distance along with information necessary for temperature compensation. Illustration 4 shows an example of the machine settings dialog.

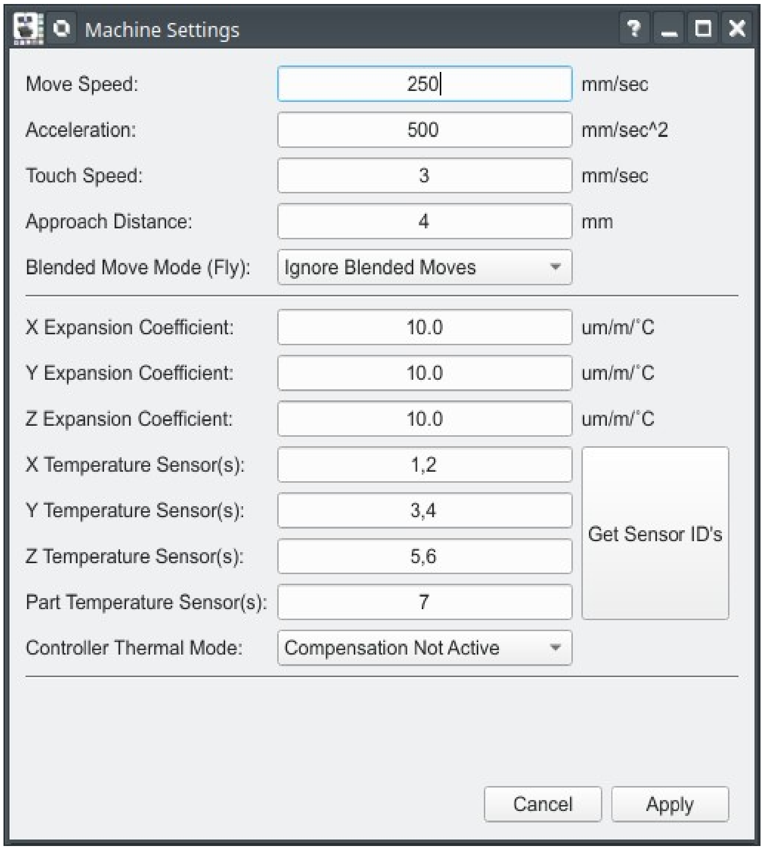


Illustration 4: Machine Settings

Table 7: Machine Options:

Option	*Description*
Move Speed	Speed of the machine when moving around the artifact; between measurement points.
Acceleration	Acceleration (and deceleration) of the CMM.
Touch Speed	Speed of the machine when measuring points.
Approach Distance	Distance from the target touch point the machine will switch between move and touch speed.
Blended Move Mode	Option for blended moves. See *Blended Move Mode* for details.
X Expansion Coefficient	Nominal expansion coefficient of the X axis of the CMM.
Y Expansion Coefficient	Nominal expansion coefficient of the Y axis of the CMM.

Option	*Description*
Z Expansion Coefficient	Nominal expansion coefficient of the Z axis of the CMM.
X Temperature Sensors	Temperature sensor identifiers for the X axis of the CMM.
Y Temperature Sensors	Temperature sensor identifiers for the Y axis of the CMM.
Z Temperature Sensors	Temperature sensor identifiers for the Z axis of the CMM.
Part Temperature Sensors	Temperature sensor identifiers for the Part.
Controller Thermal Mode	Thermal configuration of controller. See *Controller Thermal Mode* section.
Get Sensor ID's	Updates the sensor data for the X,Y,Z and part by reading the sensor data directly from the controller. *See section for I++ Temperature Sensor Data.*

Blended Move Mode

Blended Moves is continuous motion of the CMM through any path eliminating pauses at the intermediate points and maintaining a constant velocity from start to end. Using blended moves can reduce the execution time of a CMM by a significant amount. Illustration 5 shows an example of a blended move sequence.

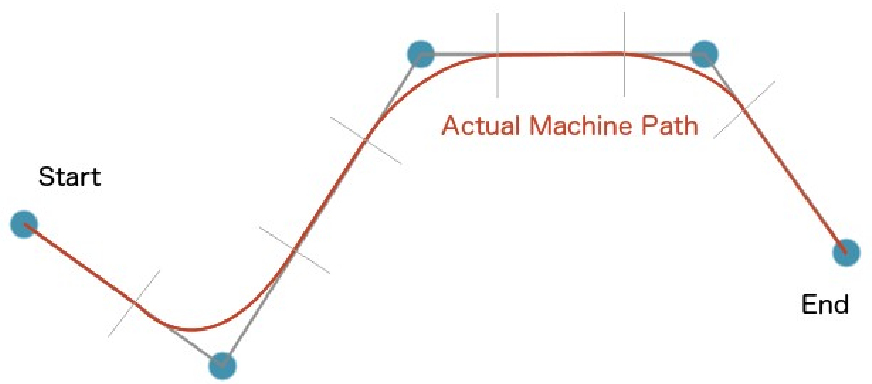


Illustration 5: Blended move example showing a series of move points and the actual path followed by the CMM.

The requirement to have this capability is that all points must be sent to the controller in advance as the controller needs this to calculate the motion of the CMM around the target points.

Table 8: Blended Move Options:

Option	*Description*
Ignore Blended Moves	No commands are sent to the controller to either enable or disable the blended moves.
Enable Blended Moves	Commands are sent to the controller to specifically enable this feature.
Disable Blended Moves	Commands are sent to the controller to specifically disable this feature.

Blended moves should be enabled on the controller unless there are known problems with this feature. Machines exist that react badly to blended moves but are rare.

Temperature Sensor Entries:

The expansion coefficients and temperature sensor data is used when temperature compensation is enabled. The temperature sensors assigned to an axis or part are entered as a comma separated list of values or (-1) if no temperature sensor exists for the axis or part.

All positive temperature sensor values must be unique. If a positive value is used more than once the sensor fields will highlight in an error state.

Table 9: Temperature Sensor Examples:

Entry	*Description*
-1	No temperature sensors exist. If temperature compensation is enabled the user must measure and enter the temperature directly.
2,3,4,5	The average of temperature sensors 2, 3, 4, and 5 will be used if the controller type is not an I++ server. The corresponding temperature input field when running a measurement will be automatically updated.

I++ Temperature Sensor Data

The sensor numbers for a CMM with an I++ controller are assigned as 1=X, 2=Y, 3=Z, and 4=Part. Using the option *Get Sensor IDs* will return those four sensors numbers regardless of the assignment of sensors on the I++ server. The function *Get Sensor IDs* will return (-1) for each axis that does not have temperature sensor hardware. It is not currently possible to get specific sensor data from an axis.

The I++ function ReadAllTemperatures() as defined in I++ DME 1.7 may be used in the future allowing access to temperatures from specific sensors. At present many of the I++ servers do not support this function.

Controller Thermal Mode

The controller thermal mode defines the current configuration for temperature compensation of the CMM. Some CMM's such as shop floor models use parametric temperature compensation that have active temperature compensation which cannot be disabled. In order to prevent double compensating for temperature effects this option must be manually set appropriate to the target machine.

Table 10: Controller Thermal Mode Options:

Option	*Controller Type*	*Comment*
Compensation Not Active	Any	Temperature compensation is off in the controller. All compensation is done by the *MeasureDirect* if enabled by the user.
Compensation Always Active	I++	Controller performs temperature compensation for the axis and part. The part expansion coefficient is sent to the controller by *MeasureDirect*. The axis expansion coefficients are known by the controller.
	Hexagon Leitz / DC	Axis temperature compensation is performed by controller and *MeasureDirect* performs compensation of the part.

Machines with active temperature compensation such as typical shop floor models have an effective expansion coefficient of 0 um/m/°C for all axis.

Artifacts

The *Artifact Settings* contain entries that are used for various measurements by *MeasureDirect*. The artifact settings are broken down into subgroups for the different measurement types and, in some cases, equipment type as is the case for step gauges.

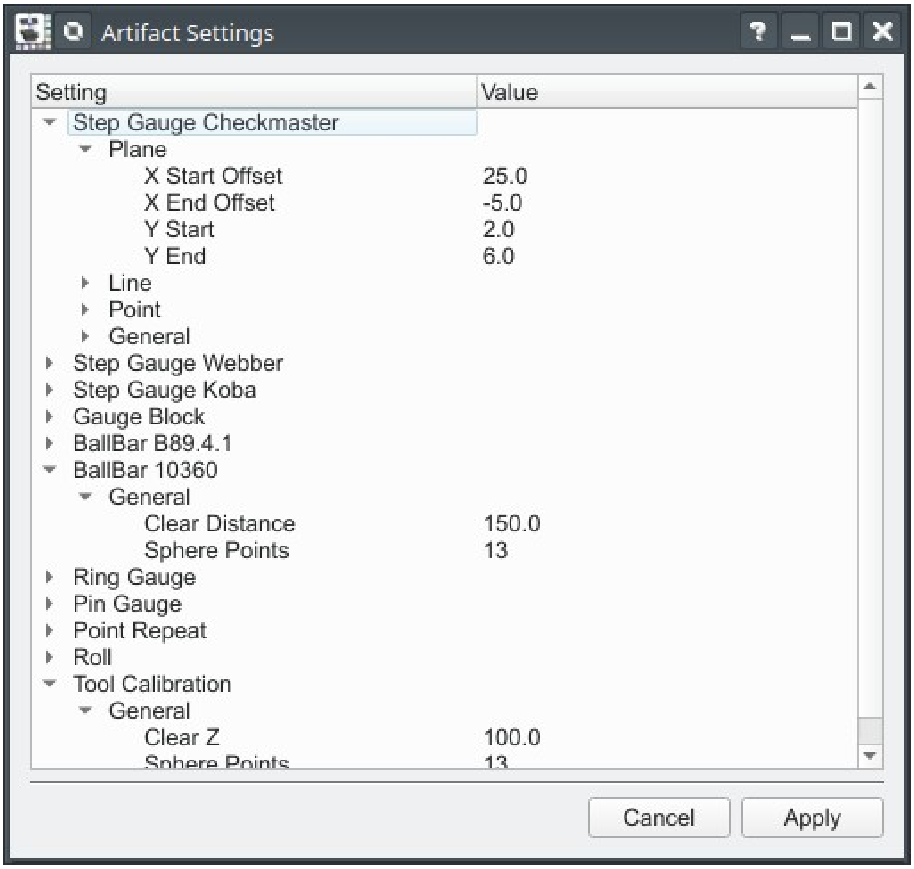


Illustration 6: Artifact Settings.

Table 11: Artifact Options:

Artifact	*Measurement*	*Option*	*Description*
Step Gauge Checkmaster	Plane	X Start Offset	Position relative the start point where the plane is measured on the step gauge.
		X End Offset	Position relative the end point where the plane is measured on the step gauge.
		Y Start	Position relative to the alignment line where the plane is measurement on the step gauge.
		Y End	Position relative to the alignment line where the plane is measurement on the step gauge.
	Line	X Start Offset	Position relative the start point where the line is measured on the step gauge.
		X End Offset	Position relative the end point where the line is measured on the step gauge.
		Z Position	Position where points are measured for the line relative to the datum plane.

Artifact	*Measurement*	*Option*	*Description*
	Point	Y Position	Position where points are measured relative to the datum line.
		Z Position	Position where points are measured relative to the datum plane.
	General	Clear Z	Position relative to the datum plane where the machine moves between features.
Step Gauge Webber	General	Clear Z	Position relative to the datum plane where the machine moves between features.
Step Gauge Koba	Plane	X Start Offset	Position relative the start point where the plane is measured on the step gauge.
		X End Offset	Position relative the end point where the plane is measured on the step gauge.
		Y Start	Position relative to the alignment line where the plane is measurement on the step gauge.
		Y End	Position relative to the alignment line where the plane is measurement on the step gauge.
	Line	X Start Offset	Position relative the start point where the line is measured on the step gauge.
		X End Offset	Position relative the end point where the line is measured on the step gauge.
		Z Position	Position where points are measured for the line relative to the datum plane.
	Point	Y Position	Position where points are measured relative to the datum line.
		Z Position	Position where points are measured relative to the datum plane.
	General	Clear Probe	Distance probe moves away from measurement target between points. Zero distance is the YZ position of the points measured along the gauge axis.
Gauge Block	Plane	Y Center	Center position relative to the position of the manual plane measurement.
		Z Center	Center position relative to the position of the manual plane measurement.
		Point Spacing	Spacing between points measured on the datum plane.
	General	Clear Z	Position relative to the Z center where the machine moves between measurement points.
BallBar B89.4.1	General	Clear	Distance from the center line of the ball bar the

Artifact	*Measurement*	*Option*	*Description*
		Distance	machine will move to between the measurement of the spheres.
		Stem Avoidance Angle	Angle of the sphere measurement to avoid. This angle represents one side from the stem so the total range avoided is twice this value.
BallBar 10360	General	Clear Z	Distance from the center line of the ball bar spheres the machine will move to between the measurement positions.
		Sphere Points	Number of points to measure on each sphere.
Ring Gauge	Plane	Plane Offset	The points measured on the ring gauge for the plane is taken at this offset value from the ring gauge diameter.
	Circle	Measurement Position	Position relative to the datum plane where the points of the ring gauge are measured.
	General	Clear Z	Position relative to the datum plane where the machine moves between points.
Pin Gauge	Plane	Plane Offset	The points measured on the pin gauge for the plane is taken at this offset value from the pin gauge diameter.
	Circle	Measurement Position	Position relative to the datum plane where the points of the pin gauge are measured.
	General	Clear Z	Position relative to the datum plane where the machine moves between points.
Point Repeat	General	Plane Sample Radius	Radial distance of plane sample points.
Roll	General	Clear Z	Position in the Z axis the machine moves between sphere measurements.
		Sphere Points	Number of points to measure on each sphere.
Calibration Sphere	General	Clear Z	Position machine moves above the center of the calibration sphere in the Z axis between tool positions.
		Sphere Points	Number of points to measure on each sphere.

The measurement of the artifacts involves the use of an alignment system. All artifact entries are relative to the internal alignment of the measurement sequence. Examples of the alignment systems are shown in the following illustrations:

Illustration 7: Internal alignment system for step gauges. X axis is along the direction of the step gauge.

The alignment consists of a plane measured on the top of the gauge block stack, a line along one side of the gauge block stack, and a starting and ending point. Some prefer to use the end face as the primary alignment plane (which is technically more correct) but due to practical reasons this is not how the alignment is handled by *MeasureDirect*.

Using the end face as the primary alignment datum may be added as an option in a future version of MeasureDirect. Using the gauge block stack for the alignment as opposed to the end face is technically not correct but the error between the two methods under ideal conditions is not enough to be a concern. The area of the end face relative to the length of the step gauge combined with poor probe repeatability is the primary reason the gauge block stack is used for the alignment and not the end face as this can contribute to more significant errors.

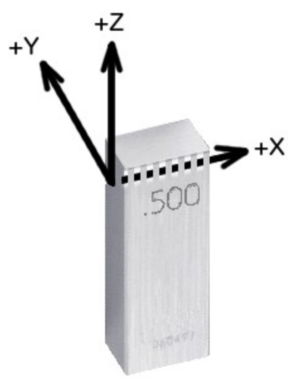


Illustration 8: Internal alignment for gauge blocks. X axis is perpendicular to the measurement faces.

The alignment for a gauge block is based on a plane measured on one of the datum faces and the axis of the current probe. The center of the manually measured plane and the artifact value of *Point Spacing* must be suitable based on the area of the gauge block measurement face.

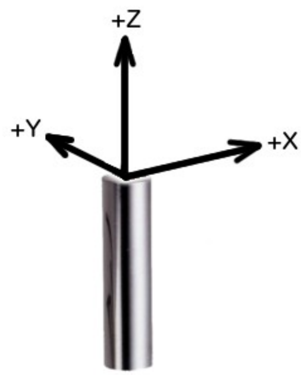


Illustration 9: Pin and ring gauge alignment. Z axis is parallel to the axis of the cylinder.

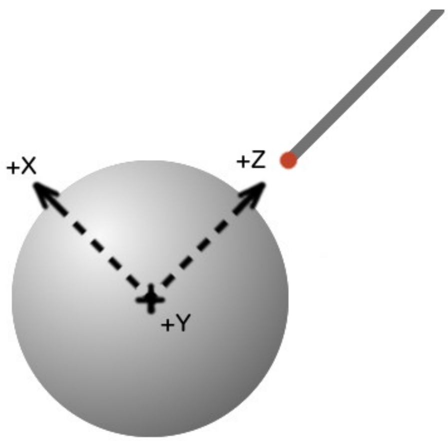


Illustration 10: Sphere alignment system. Z axis is parallel to the axis of the probe stylus.

Step Gauge Artifact Entries

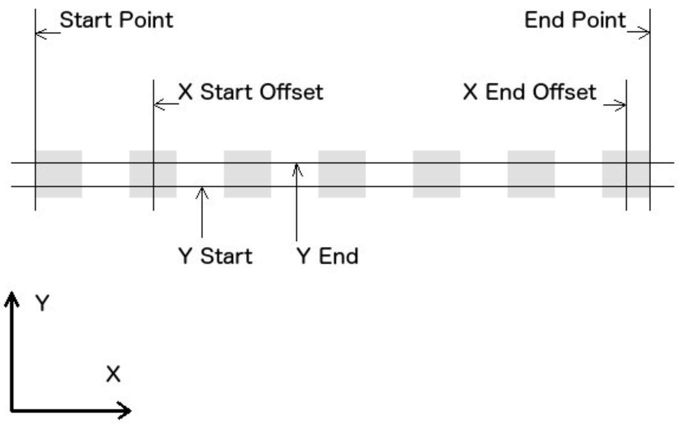


Illustration 11: Variable identification for step gauge as seen from the top.

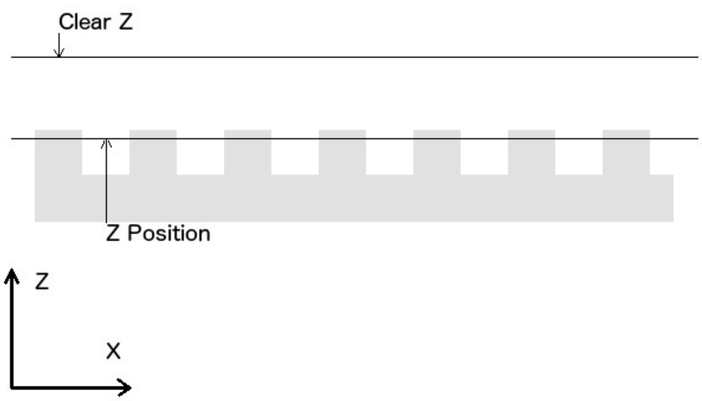


Illustration 12: Variable identification for step gauge as seen from the side.

Step Gauge Measurement Entries

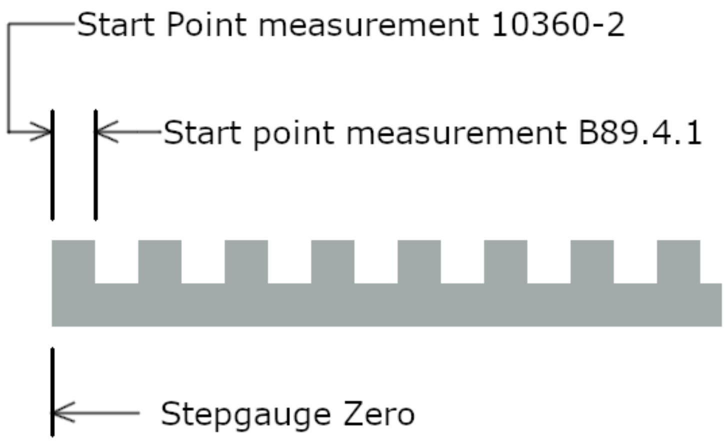


Illustration 13: Manual alignment difference between 10360-2 and B89.4.1.

When measuring a step gauge in B89.4.1 mode the starting point is taken at the position indicated with the *Measurement Start* input field. Illustration 14 shows the position and touch direction of the start point of the step gauge measurement for B89.4.1 and 10360-2 modes.

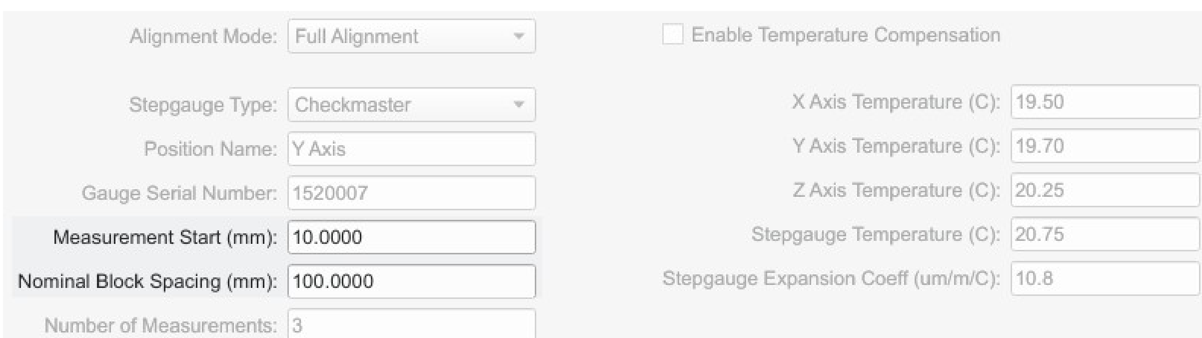


Illustration 14: Start point and increment for B89.4.1 step gauge measurements.

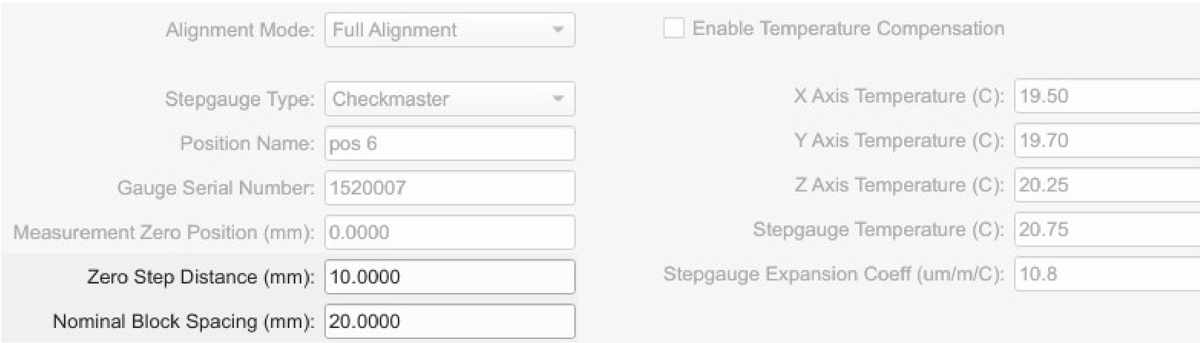


Illustration 15: Start point and nominal increment for 10360-2 step gauge measurements.

The nominal block spacing in 10360-2 mode is relative to the Zero Step Distance and not from the Measurement Zero Position. As shown in illustration 15 the measurement steps would be 0, 10, 30, 50, and so on.

Using the same zero position for ASME B89.4.1 as the 10360-2 measurement simplifies a number of data handling steps. The first point of an ASME B89.4.1 stepgauge measurement defines the location of the zero step relative to the first point even though it is not measured.

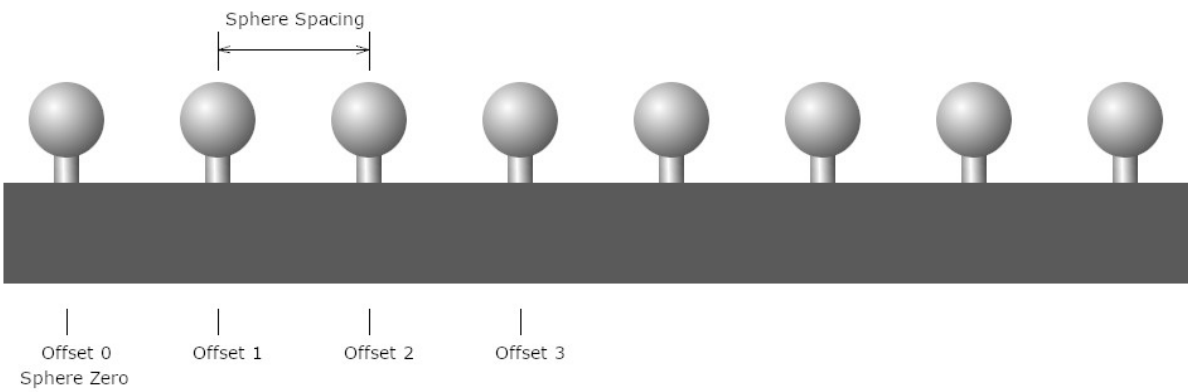


Illustration 16: Ballbar 10360 artifact.

Measurement of a ballbar 10360 artifact is a set of sphere measurements providing five unique lengths and repeated three times. The measurement pattern is identical to a typical 10360 measurement pattern on a stepgauge except spheres are measured instead of points.

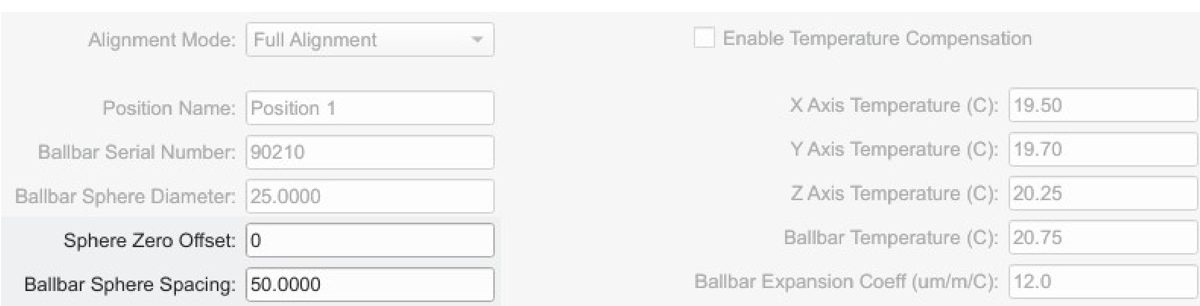


Illustration 17: Ballbar 10360 measurement entries.

The user is expected to measure two points where the first point is on the top of the measurement zero sphere and the second point is on top of the sphere representing the longest measurement length. For situations related to setup of the gauge any sphere can be used as the zero sphere provided the entry *Sphere Zero Offset* is set so that the nominal data is calculated properly.

The *Ballbar Sphere Spacing* entry is the nominal distance between the spheres and this is used to calculate where the individual sphere measurements will be done. Ideally the five lengths will be at 20, 40, 60, 80, and 100 percent of the longest length but this may not be possible depending on the actual location of the spheres so the closest pattern that matches the nominal sphere spacing is used.

There is no avoidance entries for the sphere stems. The tool used for the measurement must allow complete measurement of the sphere. The orientation of the gauge should be changed so that the stem holding the spheres is not on the same side of the sphere that will be measured by the selected tool.

Webber Step Gauge

Webber step gauges create a number of problems for generic measurement routines most notably the target points for the datum plane and line, the missing section of the end face along gauge block axis, and the spacing relative to the thickness of the gauge blocks. An image of a typical Webber step gauge is shown in illustration 18.

Illustration 18: Model of a Weber Reference Bar.

The solution to the datum target problem when using a Webber step gauge is to measure all DCC alignment points at the same location as the manual touch points. With this approach the location of the machined datum surfaces doesn't matter.

The typical calibration of these gauges does not include the negative side of the gauge block faces so only the end face can be used for bidirectional measurement which doesn't exist central to the gauge block axis.

The preferred datum system for this type of gauge should use the end face and ignore the machine datum targets. From past observations the machined datum targets tend to be misaligned to the gauge block stack by more than an acceptable amount.

Koba Step Gauge

Koba step gauges are known for stability and accuracy. The main feature is the gauge is the solid frame that almost completely encloses the calibrated blocks. An example of a Koba step gauge is shown in illustration 19.

Illustration 19: Koba Step Gauge

The measurement faces are accessible from the top or from the sides via access holes. The only downside with this type of gauge is the length of the stylus must be long enough to reach the measurement faces.

Clear Probe Option

For Koba step gauges the method to move between the measurement of features is different from the method used for other step gauges as the move is always along the tool axis and not along the alignment Z axis. The Clear Probe option is a positive value that represents how far the stylus will position before and after measuring a point along the axis of the tool stylus.

This method allows the measurement of this step gauge using a tool that can access the gauge from the top or either side. For example, to measure the two E150 positions in the YZ plane using opposing tools the alignment would be set using a third tool that can access the gauge from the top (A45B180 perhaps). Each E150 measurement would run using the alignment established by the third tool.

Tools

The tool section deals with the definition of the tool used for measurement. The tool offset is dynamically calculated based on a the fixed and rotational tool offsets, head orientation, and tool AB angles. The tip diameter is determined from a measurement of a sphere with a known size. When running as an I++ client the tool utilities are disabled as all tool functions are handled by the I++ Server.

The type of probe supported on DC or Leitz controllers is limited to touch trigger types such as TP-20 or DEA TF8. The I++ controller will allow the use of any probing technology supported by the I++ server.

The measurement of the artifacts by *MeasureDirect* does not require a tool offset that is calculated relative to any other tool offset which is common when using typical CMM software. Using a dynamically calculated tool offset has a number of advantages so it was decided to go this route. The tip diameter is stored uniquely for each tool orientation by measuring a known sphere and calculating the stylus diameter from the difference in size.

Tool Head Orientation

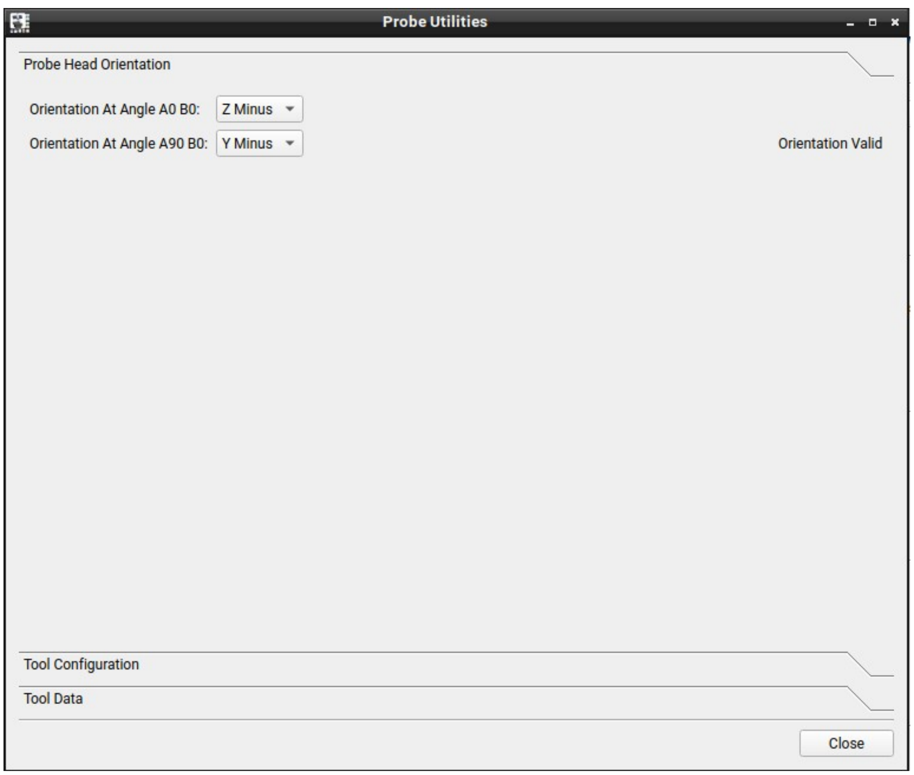


Illustration 20: Probe Utilities - Probe Head Orientation page.

The orientation section of the *Tool Utilities* defines the probe head orientation on the CMM. The orientation is based on knowing the direction of the tool at head angles <A0,B0> and <A90,B0>.

For a typical bridge machine with a kinematic of YXZ and the probe head mounted with the LED facing the front of the CMM then head angle <A0,B0> would point in the Z minus direction and Y minus direction when indexed to <A90,B0>.

Selecting invalid axis options will result in the text on the right side changed to *Orientation Invalid* and the *Tool Configuration* and *Tool Data* widgets will be disabled.

Tool Configuration

The *Tool Configuration* section allows the definition of the fixed and rotational offsets for the named tool. Illustration 21 shows an example of a tool configuration.

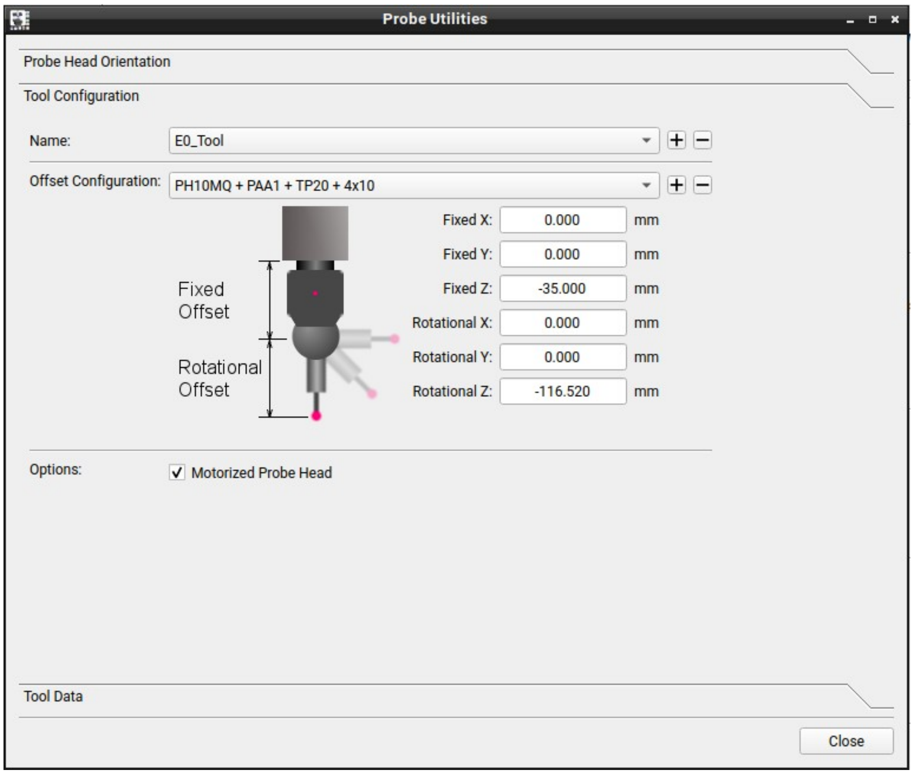


Illustration 21: Probe Utilities - Tool Configuration page.

The offset configuration has inputs for fixed and rotational components. The fixed offset is constant regardless of the head AB angle where the rotational offset is combined with the head AB angle to calculate the functional tool offset. The entry values for the two offsets is at the default head angle of <A0,B0> and the current head orientation settings.

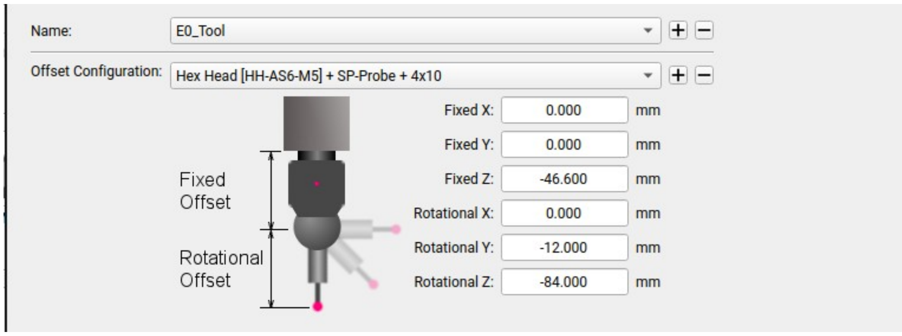


Illustration 22: Example of configuration with a complex offset.

Illustration 22 describes a Hexagon probe head with a 12 mm offset in the Y axis as setup on a typical bridge CMM. The 12 mm offset is part of the rotational offsets so when indexing the A angle to 90 the 12 mm offset would end up in the Z direction of the CMM.

Using two length values for the fixed and rotational part of the head instead of two XYZ coordinates would be preferred but this doesn't work correctly with many of the Hexagon heads.

The MeasureDirect utility will automatically create a set of tools and offset configurations that are commonly used for testing if the file 'tool_data.xml' is not found or the number of configuration entries is zero.

Tool Configuration Builder

Offset configurations can be created using the *Tool Configuration Builder* by clicking on the add button to the right of the active offset configuration. Illustration 23 shows the *Tool Configuration Builder* with a sample tool build.

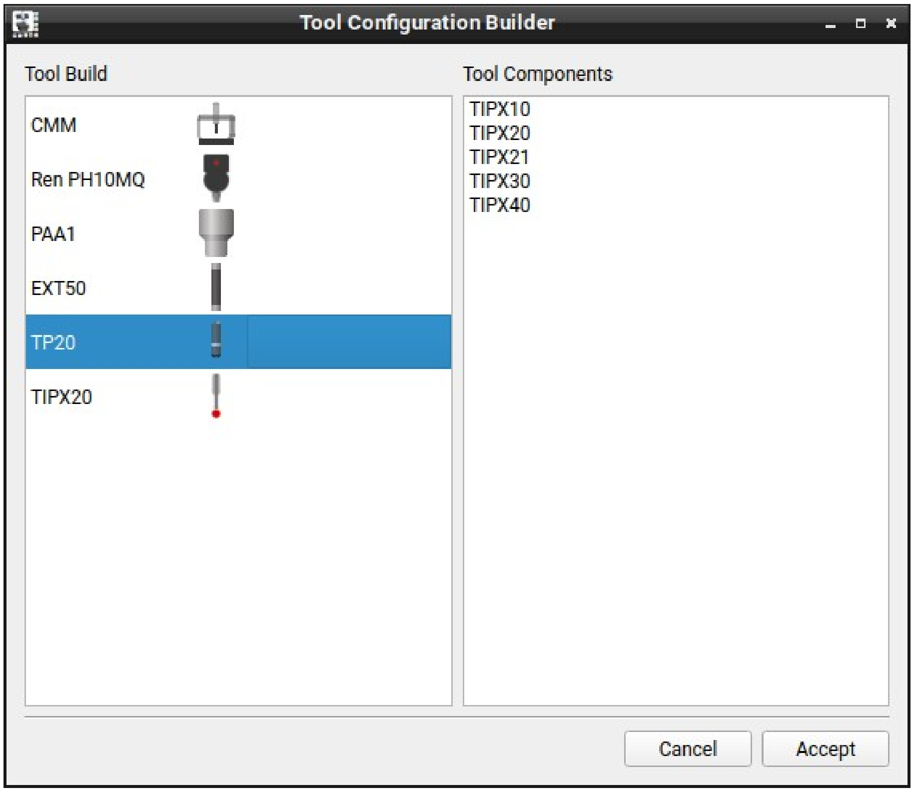


Illustration 23: Tool configuration builder dialog.

Table 12: Tool Configuration Builder Options:

Option	*Description*
Tool Build	Shows a list of all components selected for the tool.
Tool Components	List of all available components that can be attached to the selected tool build item.
Accept	Create a new offset configuration based on the current tool build.
Cancel	Close the dialog. All changes are lost.

The tool build is created by highlighting a tool build entry on the left side and choosing a tool component from the right side. The tool component is added to the tool build by double-clicking on the tool component with the mouse.

The Accept option will be greyed if the tool build is not complete to the stylus or the offset configuration already exists.

The Tool Configuration Builder creates a new offset configuration entry. The offsets can be manually manipulated if needed but should not be necessary if the tool is built correctly.

The options for stylus only show the stylus length and not the tip diameter. The tip diameter can be manually set or determined by performing a calibration.

Tool Data

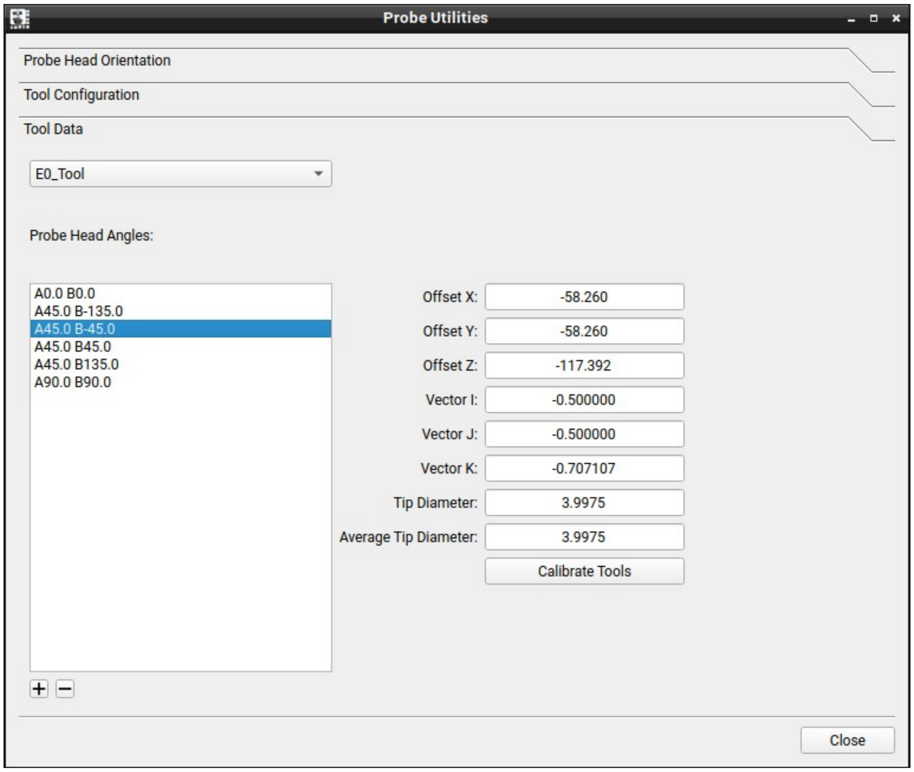


Illustration 24: Probe Utilities - Tool Data page.

The Tool Data section shows a list of head AB angles associated with a specific tool configuration. The offset and vector fields for the selected tool angle are automatically calculated based on the configuration associated with the tool name. The tip diameter can be manually entered or determined by running a calibration cycle. The *Average Tip Diameter* shows the average tip size for all selected head angles.

Adding Tool Angles

New tool angles are created by clicking on the *Add* button (+). Illustration 25 shows the A*dd Angles* dialog that appears when adding one or more new tool angles.

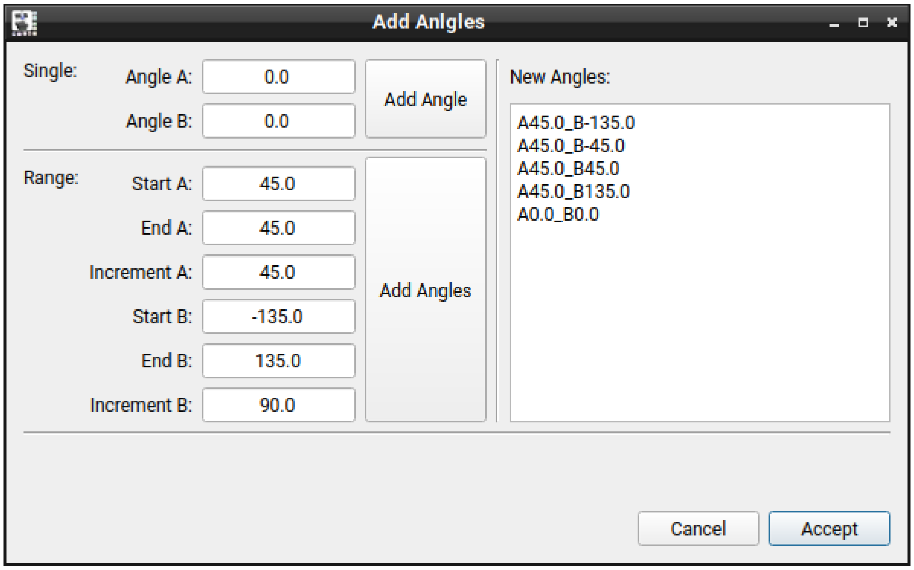


Illustration 25: Dialog for adding a single or multiple tool angles.

Tool angles can be added individually or by specifying a range. A unique list of angles that will be added to the active tool is displayed in the *New Angles* list. Pressing *Accept* will add the new angles to the existing angle list of the active tool.

Table 13: Add Angle Options:

Option	*Description*
Angle A	Entry for the A angle when adding a single angle.
Angle B	Entry for the B angle when adding a single angle.
Add Angle	Adds a single angle position using the Angle A and Angle B values.
Start A	Starting angle for the range of A angles.
End A	Ending angle for the range of A angles.
Increment A	Increment of the A axis between the start and end A angle.
Start B	Starting angle for the range of B angles.
End B	Ending angle for the range of B angles.
Increment B	Increment of the A axis between the start and end B angle.
Add Angles	Add all tool angles from the start and end AB angles at the increment specified.
New Angles	A list of angles that will be added to the angle list for the active tool.

Duplicate angles are automatically removed when combined with the angle list for the active tool.

Calibrate Tools

This option will calibrate the selected tools. After pressing the *Start* button a single point is manually measured on the reference sphere then all selected tool positions will be calibrated automatically. The tool calibration only determines the working tip diameter as all offsets are dynamically calculated (inferred calibration).

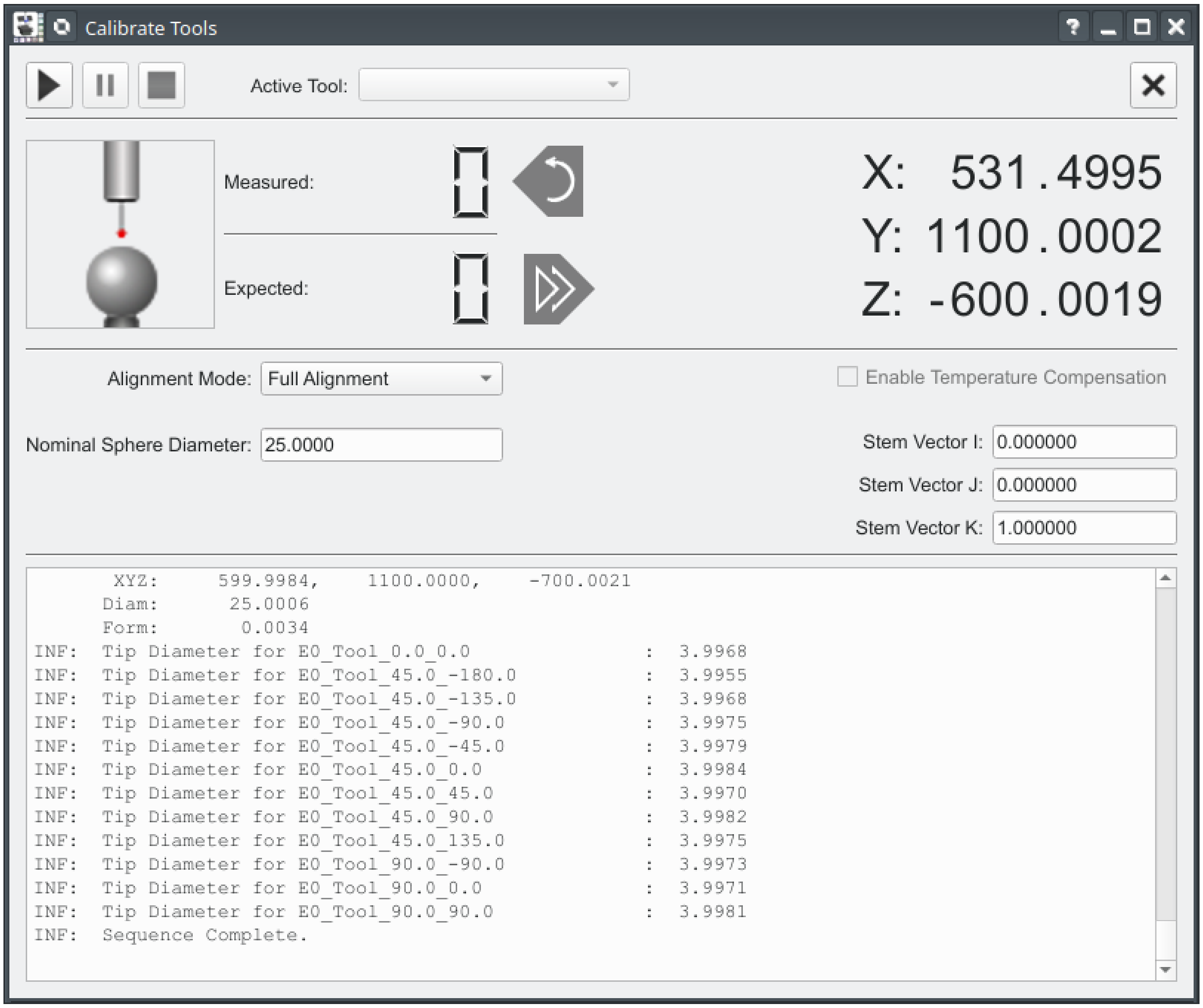


Illustration 26: Tool calibration dialog. One manual point on sphere is required to start.

Table 14: Calibrate Tool Options:

Option	*Description*
Nominal Sphere Diameter	Nominal diameter of the reference sphere used for the tool calibration.
Stem Vector IJK	Direction from the sphere stem connection point to the center of the sphere. Touch points will avoid this vector by +/- 60 degrees.

Measure

The measure section contains all the measurement tests that can be run by *MeasureDirect*.

Table 15: Measurement Options:

Option	*Description*
Step Gauge 10360	Measurement of a step gauge as described by 10360-2. See note 1, 2.
Step Gauge B89.4.1	Measurement of a step gauge as described by ASME B89.4.1. See note 2.
Step Gauge Square	Measurement of the step gauge for the purpose of updating axis squareness errors. See note 4.
Ballbar B89.4.1	Measurement of a ball bar as defined by ASME B89.4.1:1997
Ballbar 10360	Measurement of a ball bar. Unlike the B89.4.1 ballbar this is a bar with a series of spheres mounted at regular intervals.
Gauge Block 10360	Measurement of a gauge block. The gauge block can be a supplemental short measurement for a laser or one of the five lengths along a measurement line. See note 3.
Sphere 10360 Pftu	Measurement of a sphere using a single tool tip as defined by 10360-5:2010 Pftu. This is identical to the ISO 10360-2:2001 'P' test.
Ring Gauge	Measurement of a ring gauge. See note 5
Pin Gauge	Measurement of a pin gauge. See note 5
Sphere Repeat Rpt	Measurement of a sphere as described by ASME B89.4.10360-2:2008 Rpt and identical to the sphere repeatability test from the ASME B89.4.1:1997 ball bar standard.
Point Repeat	Perform a single point repeatability test.
Roll	Axis roll from opposing tool angles measuring a sphere in two locations. See note 6
Laser	Measurement using an external device such as a laser. The measurement can be for data collection or testing as per 10360-2.

Table 16: Measurement Option Notes:

Note 1:	The measurement of the step gauge includes an additional zero step measurement that is not defined by the 10360-2 standard. This is useful for troubleshooting and can be ignored when reporting the data.
Note 2:	The alignment of the step gauge is a conventional 3-2-1 plus an end point. Alignment using only the end face may be added in the future.
Note 3:	The alignment is based on a plane measurement on one face of the gauge block and the axis of the tool. No other surfaces of the gauge block are measured.
Note 4:	The measurement of the step gauge with seven points producing six lengths with the first length at the minimum bidirectional step gauge distance. Three symmetrical, unidirectional, lengths can be extracted from this data. Four 3D volume measurements

	of the step gauge will produce twelve unique measurement lengths suitable for updating squareness errors on a CMM.
Note 5:	Ring and Pin gauge measurements are virtually identical other than the ring gauge measures an inside diameter where the pin gauge measures an outside diameter.
Note 6:	Roll of the axis is intended to be used with the third axis of a CMM (Z for a kinematic of XYZ or Y for a kinematic of XZY). This should work for the second kinematic axis although it would be unusual to use it for this purpose. This will not work for the first kinematic axis and should always return a gradient around 0 um/m regardless of the real error. The goal of this utility is simple correction or verification.

Measure Interface

The interface when running any of the measurement sequences other than the laser is nearly identical with only unique input fields related to the type of measurement selected. An example of the measurement interface for the step gauge is shown in illustration 27.

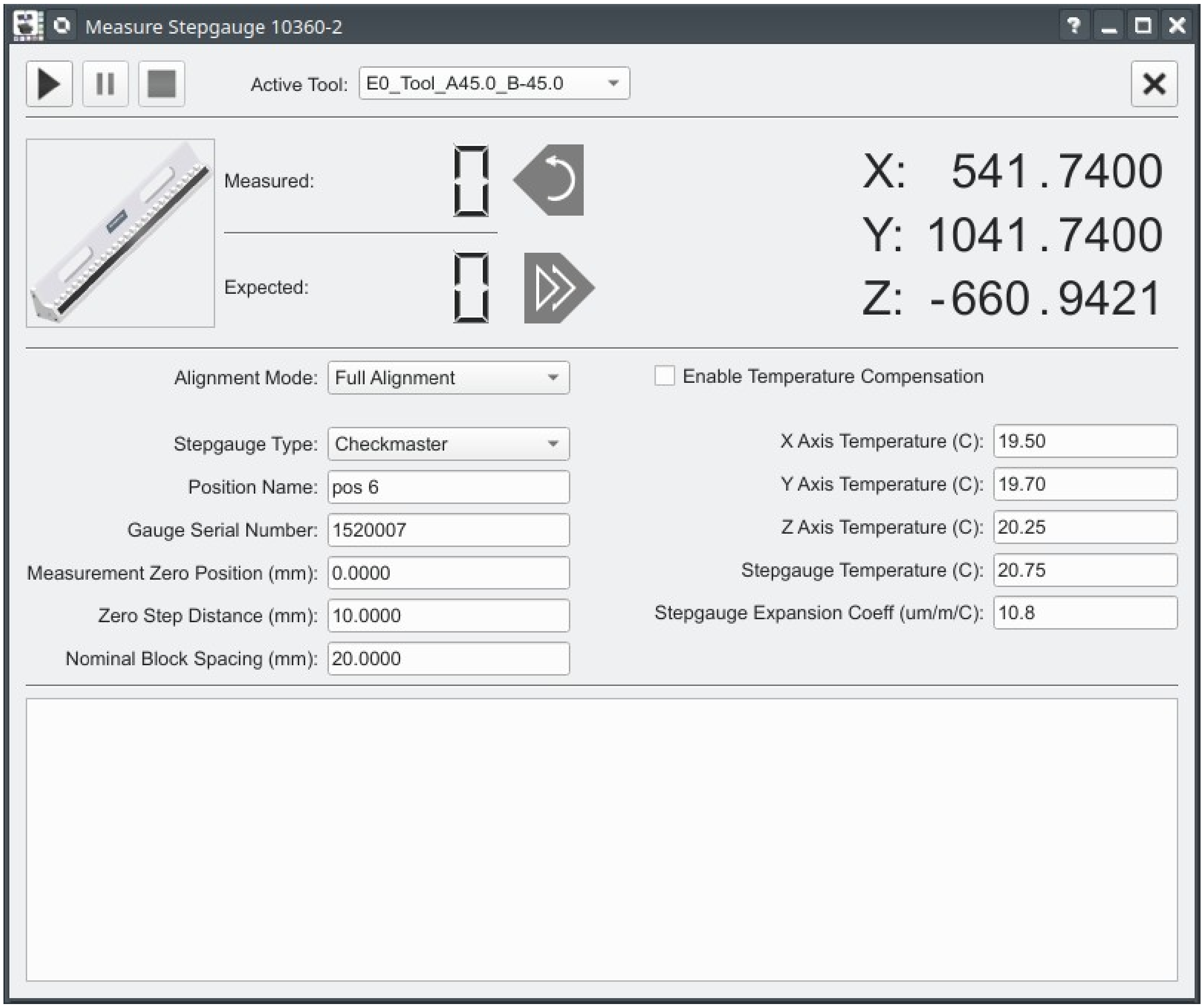
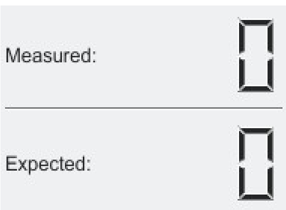
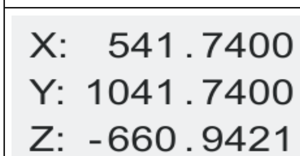


Illustration 27: Common measurement interface.

Table 17: Measure Interface Options:

Item or Option	*Description*
	Buttons for Play, Pause, and Stopping the execution of a measurement.
Active Tool	Selection for tool to perform the measurement.
	Close button. Functionally identical to using the close button at the top of the window.

Item or Option	*Description*
	Icon representing the currently active feature or function of the measurement sequence.
	Point counter. The value on the top of the horizontal divider shows the actual number of measured points where the bottom shows the required number of points.
	Erase hit button. Erase the last measurement point.
	Next button. Proceed to next feature or step. When the last point of a feature is measured the software will wait for the *Next* button to continue or the Done or End button on the jogbox. If an additional point is measured the software will assume the intention is to simply move on to the next measurement feature or step.
	Coordinate display.
Alignment Mode	Options for the measurement alignment. See *Alignment Mode* section for details.
Enable Temperature Compensation	Measurement of the Step Gauge, Ball Bar, or Gauge Block can use temperature compensation.

Alignment Mode

There are four options for alignments. Some options are not available for certain types of measurements but the list is generic for all measurement types. The alignment options are described in the following table:

Table 18: Alignment Options:

Option	*Description*
Full Alignment	The alignment consists of a manual measurement followed by a DCC measurement of the alignment features. This is the default option.

Option	*Description*
Skip Manual Alignment	The manual alignment is skipped and the measurement starts at the beginning of the DCC alignment. It is suitable if the position of the artifact has not moved from the last measurement.
Skip Alignment	The alignment from the previous measurement is used. No manual or DCC alignment is performed.
Alignment Only	Only run the alignment part of the measurement sequence. This consists of the manual alignment followed by the DCC alignment.

Some measurement functions, such as Roll or probe calibration, only use the Full Alignment option. The alignment options are implemented where it makes sense to do so.

Temperature Compensation

When temperature compensation is used, and not handled by the controller, a small information dialog will appear to the right of the measurement window showing details related to temperature compensation. An example of this dialog is shown in illustration 28.

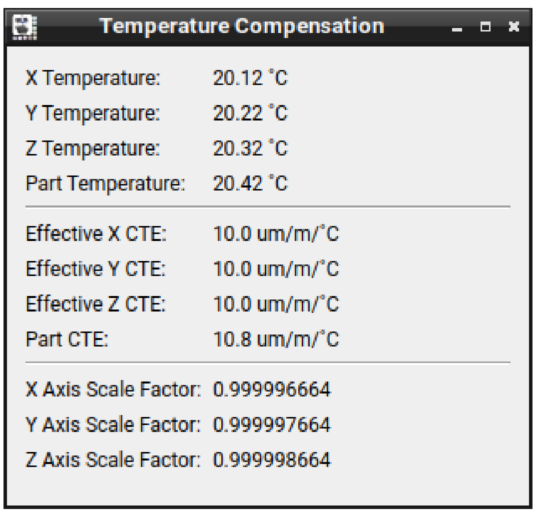


Illustration 28: Temperature compensation information dialog.

The temperature compensation information dialog shows all input temperatures and known expansion coefficients along with the calculated scale factor corrections for each axis. When the controller handles part of the compensation the expansion coefficients for the axis will show an effective CTE of 0 um/m/°C.

When using controllers such as I++ with active temperature compensation the controller handles all temperature compensation functions and this dialog is not displayed. The part expansion coefficient is sent to the controller with the command SetProp(Part.XpanCoefficient(XXX)).

Measurement Options

Each type of measurement has specific options as described in the following sections:

Step Gauge 10360

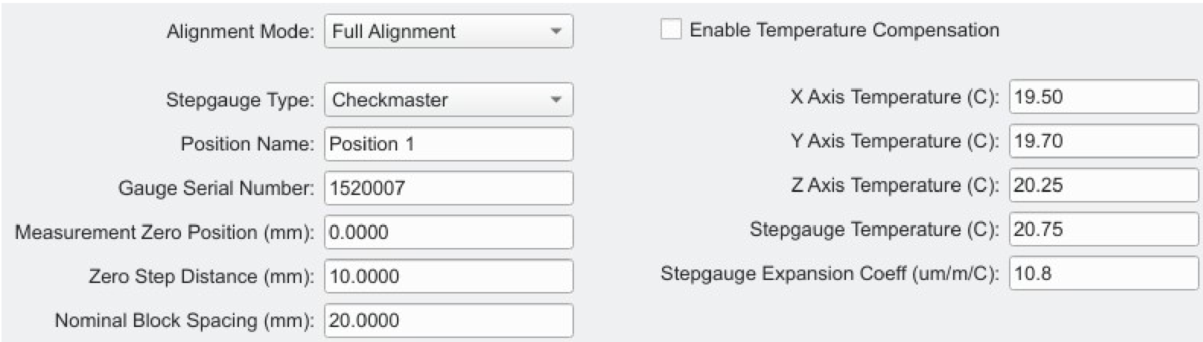


Table 19: Step Gauge 10360 Options:

Option	*Description*
Step Gauge Type	Type of step gauge used for the measurement.
Name	Name of the measurement. This will appear as part of the name of the output file and inside the output file data.
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Step Gauge Temperature	Temperature of the step gauge. This could be manually input or entered automatically depending on the temperature sensor setup.
Gauge Serial Number	Unique identification of the step gauge used for the measurement.
Step Gauge Expansion Coeff.	Expansion coefficient of the step gauge
Measurement Zero Position	Nominal position on the step gauge that is used as the first point of the step gauge measurement. Typically the first point is measured at the zero or reference step but not always.
Zero Step Distance	This is the distance for the zero step measurement. This is the distance from the measurement of the reference step to the first measurement face of the step gauge. The measurement is done as a bidirectional measurement.
Nominal Block Spacing.	The nominal unidirectional distance between the gauge block steps.

Comments:

- The alignment of the step gauge is a standard 3-2-1 plus an end point. For practical reason the alignment of the step gauge does not use the end face as a primary datum.

- The 10360-2 requirement is to measure five lengths, three times. This measurement includes a zero step measurement which is ignored when reporting the data but is useful for evaluation of the calibrated tip diameter.

Step Gauge B89.4.1

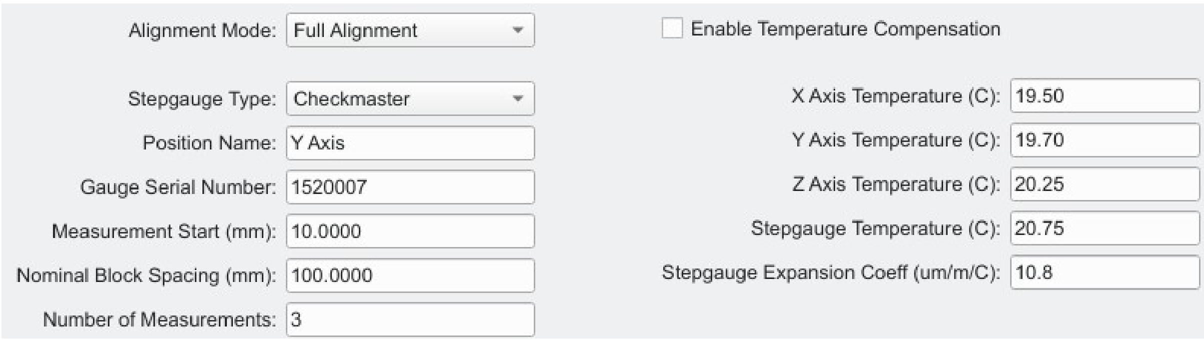


Table 20: Step Gauge B89.4.1 Options:

Option	*Description*
Step Gauge Type	Type of step gauge used for the measurement.
Name	Name of the measurement. This will appear as part of the name of the output file and inside the output file data.
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Step Gauge Temperature	Temperature of the step gauge. This could be manually input or entered automatically depending on the temperature sensor setup.
Gauge Serial Number	Unique identification of the step gauge used for the measurement.
Gauge Expansion Coeff.	Expansion coefficient of the step gauge
Measurement Start	Position on the step gauge for the starting measurement point.
Nominal Block Spacing.	The nominal unidirectional distance between the measurement steps.
Number of Measurements	Total number of measurements of the step gauge.

Comments:

- The alignment of the step gauge is a standard 3-2-1 plus an end point. For practical reason the alignment of the step gauge does not use the end face as a primary datum.

- All points are measured unidirectionally on the step gauge so effects of the tool calibration tip diameter have no impact on the results.

Step Gauge Square

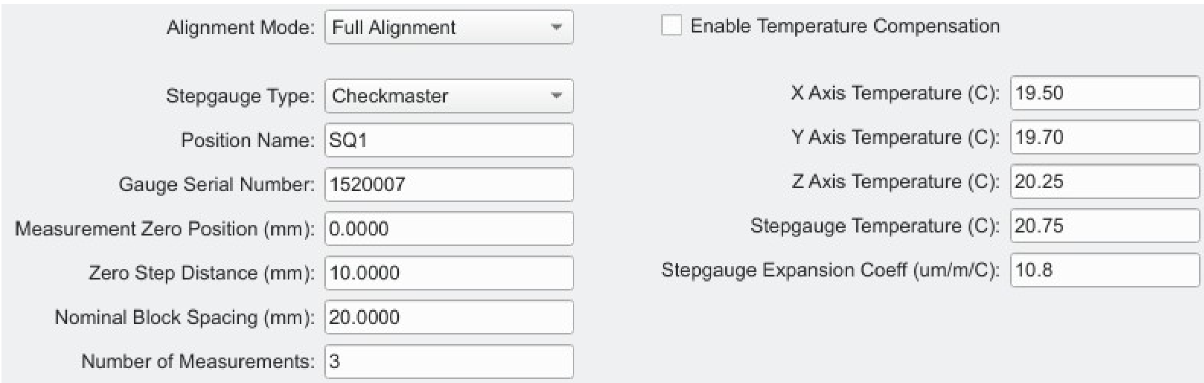


Table 21: Step Gauge Square Options:

Option	*Description*
Step Gauge Type	Type of step gauge used for the measurement.
Name	Name of the measurement. This will appear as part of the name of the output file and inside the output file data.
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Step Gauge Temperature	Temperature of the step gauge. This could be manually input or entered automatically depending on the temperature sensor setup.
Gauge Serial Number	Unique identification of the step gauge used for the measurement.
Gauge Expansion Coeff.	Expansion coefficient of the step gauge
Measurement Zero Position	Nominal position on the step gauge that is used as the first point of the step gauge measurement. Typically the first point is measured at the zero or reference step but not always.
Zero Step Distance	This is the distance for the zero step measurement. This is the distance from the measurement of the reference step to the first measurement face of the step gauge. The measurement is done as a bidirectional measurement.
Nominal Block Spacing.	The nominal unidirectional distance between the gauge block steps.
Number of	Total number of measurements of the step gauge.

Option	*Description*
Measurements	

Comments:

- The alignment of the step gauge is a standard 3-2-1 plus an end point. For practical reason the alignment of the step gauge does not use the end face as a primary datum.
- The measurement produces six lengths (seven points) of which the zero length is used for troubleshooting tool calibration issues and the remainder can be used to extract three unidirectional lengths for squareness updates.

Ballbar B89.4.1

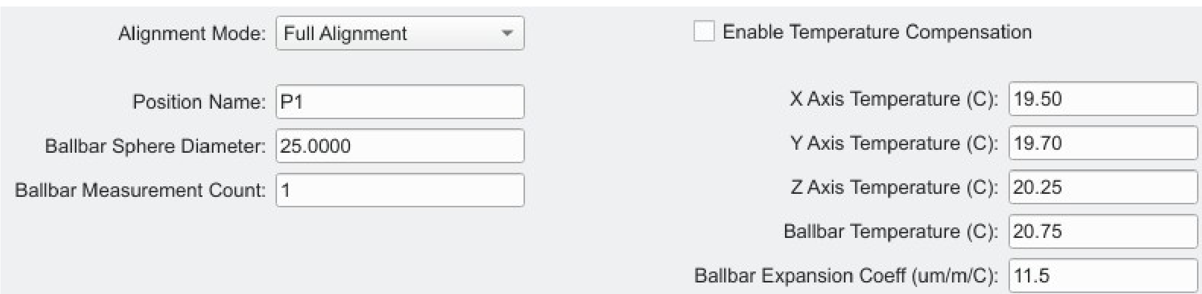


Table 22: Ballbar B89.4.1 Options:

Option	*Description*
Position Name	Name of the measurement position.
Ballbar Sphere Diameter	Nominal diameter of the ballbar spheres.
Ballbar Measurement Count	The number of times to measure the ballbar.
Ballbar Expansion Coefficient	Expansion coefficient of the ballbar.
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Ballbar Temperature	Temperature of the ballbar. This could be manually input or entered automatically depending on the temperature sensor setup.

Ballbar 10360

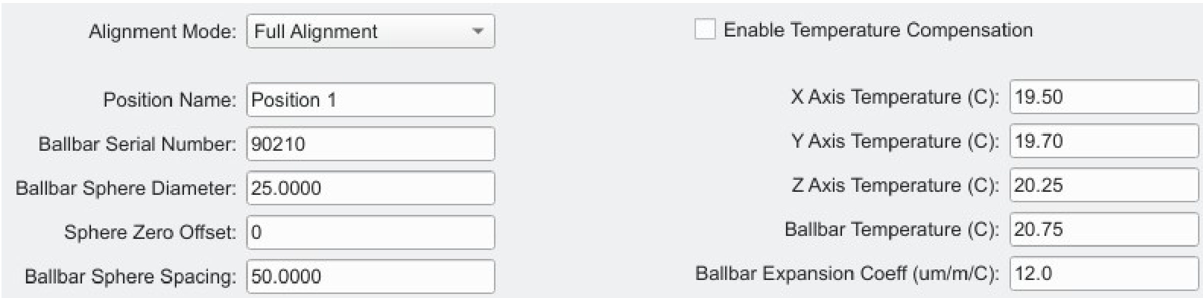


Table 23: Ballbar 10360 Options:

Option	*Description*
Position Name	Name of the measurement. This will appear as part of the name of the output file and inside the output file data.
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Ballbar Temperature	Temperature of the ballbar. This could be manually input or entered automatically depending on the temperature sensor setup.
Ballbar Serial Number	Unique identification of the ballbar used for the measurement.
Ballbar Expansion Coeff.	Expansion coefficient of the ballbar
Ballbar Sphere Diameter	Nominal diameter of the ballbar spheres.
Sphere Zero Offset	Index describing which sphere is used as the zero sphere. The first sphere would have an index of 0, the second would be 1, the third would be 2, and so on.
Ballbar Sphere Spacing.	The nominal distance between the ballbar spheres.

Comments:

- The alignment of the ballbar uses the location of the first and last sphere along with the axis of the active probe.
- The measurement is five lengths repeated three times. This measurement should be supplemented with a corresponding gauge block measurement for reporting purposes.

Gaugeblock 10360

Table 24: Gaugeblock 10360 Options:

Option	*Description*
Name	Name of the measurement. This will appear as part of the name of the output file and inside the output file data.
Gauge Serial Number	Unique identification of the gauge block used for the measurement.
Nominal Length	The nominal length of the gauge block.
Gauge Expansion Coeff.	Expansion coefficient of the gauge block
X Axis Temperature	Temperature of the X axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Y Axis Temperature	Temperature of the Y axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Z Axis Temperature	Temperature of the Z axis of the machine. This could be manually input or entered automatically depending on the temperature sensor setup.
Gauge Temperature	Temperature of the gauge block. This could be manually input or entered automatically depending on the temperature sensor setup.

Comments:

- The alignment for the gauge block is based on a single plane measurement on one face of the gauge block and the axis of the tool. The center of the manual plane measurement is the center position of the DCC measurement.

Ring Gauge

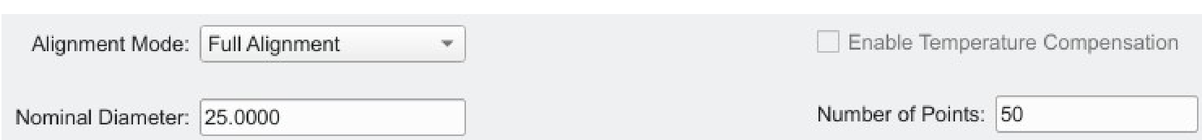


Table 25: Ring Gauge Options:

Option	*Description*
Nominal Diameter	Diameter of the ring gauge

Option	*Description*
Number of Points	Number of points to measure on the ring gauge.

Pin Gauge

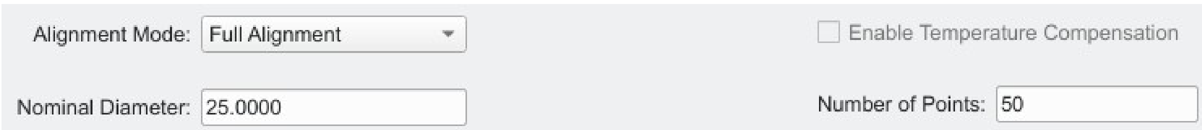


Table 26: Pin Gauge Options:

Option	*Description*
Nominal Diameter	Diameter of the pin gauge
Number of Points	Number of points to measure on the pin gauge.

Sphere Pftu

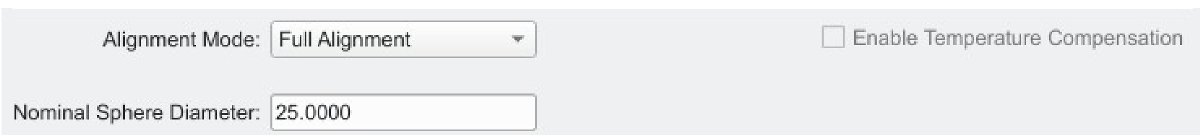


Table 27: Sphere Pftu Options:

Option	*Description*
Nominal Sphere Diameter	Diameter of the sphere that will be used for the Pftu test.

Comments:

Defined in 10360-5:2010 Pftu and identical to the ISO 10360-2:2001 P test.

Sphere Repeat

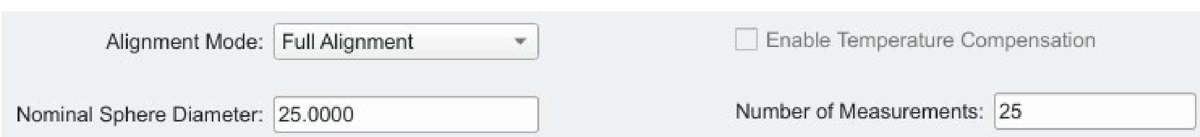


Table 28: Sphere Repeat Options:

Option	*Description*
Nominal Sphere Diameter	Diameter of the sphere that will be used for the repeatability test.
Number of Measurements	Number of times to measure the sphere.

Comments:

- Standard repeatability test as defined by ASME B89.4.10360-2:2008 Rpt or ASME B89.4.1:1997.

Point Repeat

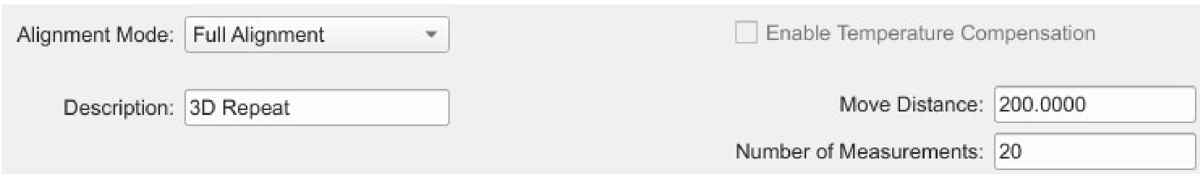


Table 29: Point Repeat Options:

Option	*Description*
Description	Name of the measurement.
Move Distance	Distance the machine will move between each measured point. Motion is a right angle to the measurement datum plane.
Number of Measurements	Number of measurement points.

Comments:

- This repeatability can be used to measure the repeatability of the CMM along the touch axis and the ability of the machine to position perpendicular to the touch axis. The point data from this measurement must be properly processed to separate the two parts.

Roll

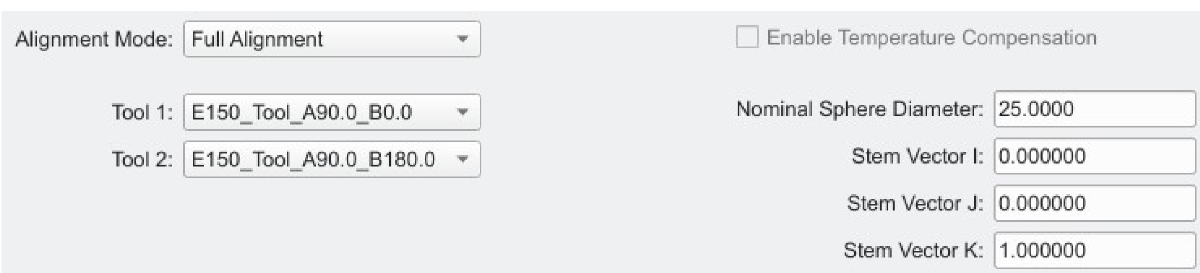


Table 30: Roll Options:

Option	*Description*
Tool 1	Selection of tool for measuring sphere positions 1 and 4.
Tool 2	Selection of tool for measuring sphere positions 2 and 3.
Nominal Sphere Diameter	Diameter of the sphere that will be used for the roll test.
Stem Vector IJK:	Direction of sphere stem. Points will not be measured within +/- 60 deg. of this vector.

Comments:

- The measurement involves measuring a sphere at two different positions along the test axis using the two named tools. The roll is calculated based on the change in the relative position along the test axis. The test axis is determined from the difference in the sphere positions with the Z given priority over any other axis.
- The tool length should be as long as practical and the difference in position between the lower and upper sphere should be as large as practical in order to produce the best results.

Step Gauge Distance Entries

When measuring a step gauge two entries are used to calculate the proper target locations for DCC measurements:

- Zero Step Distance
- Nominal Block Spacing

When measuring a step gauge in B89.4.1 the entry Zero Step Distance is replaced by the Measurement Start entry.

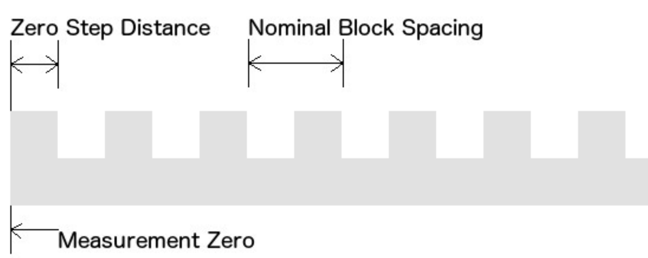


Illustration 29: step gauge distance entries.

Referring to illustration 29 *Measurement Zero* is the datum face of the step gauge. The *Zero Step Distance* is the nominal distance to the first face of the step gauge from the *Measurement Zero* face. The *Nominal Block Spacing* entry represents the typical distance between the gauge blocks.

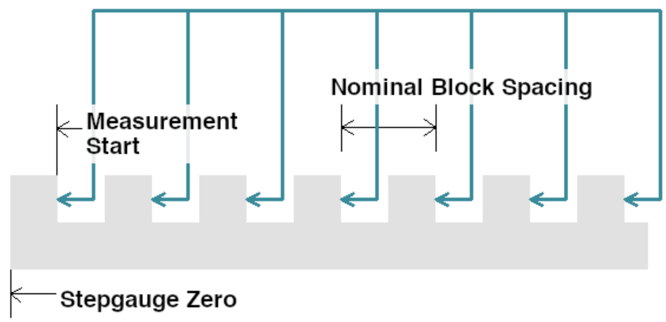


Illustration 30: Step gauge distance entries when running in B89.4.1 mode.

When running a step gauge in B89.4.1 mode all points are measured unidirectionally. The zero point is offset by the value of *Measurement Start* input field and will end up at the zero face of the gauge. All measurement values are shown from the step gauge zero which simplifies associating the proper nominal to each measured point.

Webber Distance Entries

The distance entries for a Webber step gauge require special consideration. The *Zero Step Distance* and *Nominal Block Spacing* entries may be the same depending on the position of the zero point. If *Measurement Zero* is not at the end face the *Zero Step Distance* should be around 8 mm.

The calibration of Webber step gauges usually doesn't involve both faces of each gauge block so only the reference end face of the gauge should be used for measurement purposes.

The nominal of the unmeasured face of the step gauge can be assumed to be the nominal width of the individual gauge blocks away from the calibrated face. The measurement uncertainty would increase by the tolerance of the gauge blocks used for this kind of step gauge but it is believed the individual block tolerances are low enough where the error would be minimal.

Step Gauge Zero Step Distance Measurement

The step gauge Zero Step Distance measurement is not a zero length measurement despite the name but the shortest bidirectional measurement that can be performed on the step gauge. This measurement exists for two reasons:

- Identification of tool calibration problems.
- Allow subtraction of the tool calibration error from the step gauge measurement when used for gradient corrections or squareness updates.

The tool calibration is critical when performing bidirectional measurements and is one of the primary reasons the configuration of the tool is defined with the specifications of the machine. Illustration 31 shows the effect on an E150 measurement with a bidirectional measurement error of 0.003 mm likely due to a tool calibration issue. When using this data for some form of correction the zero length measurement face should be used and not the zero face of the step gauge.

Meas	Nominal	Actual	Dev	Range	Stdev
1	9.99990	10.00310	0.00320	0.00111	0.00060
2	209.99290	209.99506	0.00216	0.00168	0.00084
3	409.99540	409.99810	0.00270	0.00037	0.00021
4	609.99950	610.00266	0.00316	0.00078	0.00040
5	810.00090	810.00301	0.00211	0.00104	0.00055
6	1010.00030	1010.00473	0.00443	0.00104	0.00053

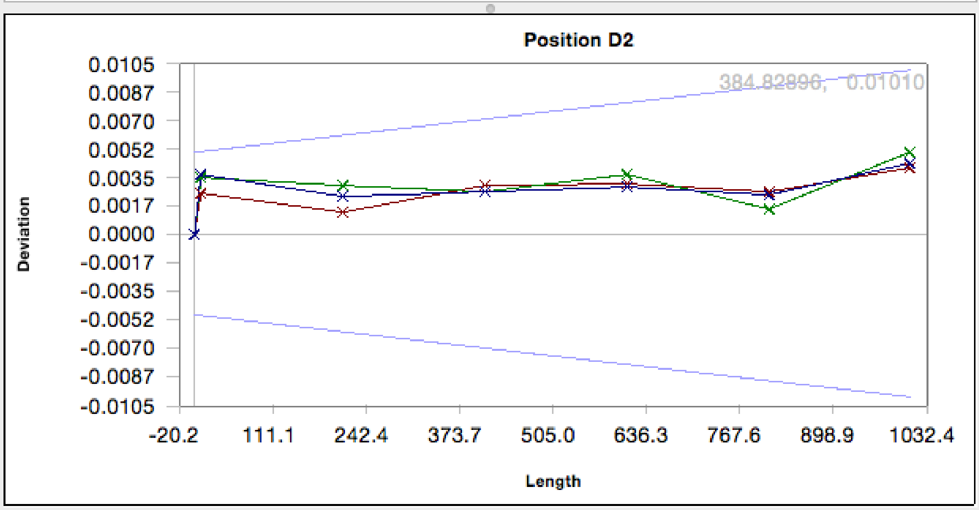


Illustration 31: Image showing effect of a probe calibration problem that shows up during bidirectional measurements.

Roll Measurement

The roll measurement returns a value for the correction gradient of the roll error for the measured axis. Illustration 32 shows an example of a roll measurement based on the position of a sphere and two opposing tools.

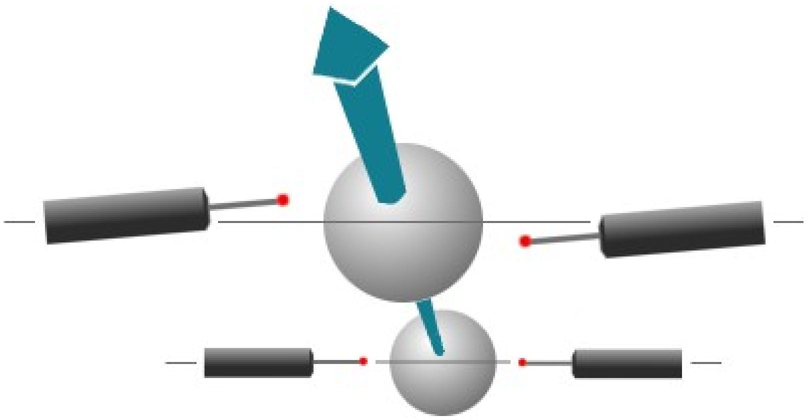


Illustration 32: Roll measurement example.

The roll measurement will produce a result for the second or third kinematic axis of any CMM. The roll from the first kinematic axis cannot be measured using opposing tools and should always produce a result of zero if measured properly.

Performing this test with *MeasureDirect* requires the two tools to be selected. With the sphere in the first position a measurement with both tools is performed and then repeated in the second sphere position. The result can be viewed in *MeasureView.*

The gradient can be directly added to the existing compensation map to remove the error. The sign of the gradient is displayed in two forms (CCW=Positive and CW=Positive) and the one used to sum with the existing compensation map data is based on the properties of the target compensation error map.

The default axis is Z unless the difference between the sphere positions in Z is less than the current default of 100 mm. The result from the roll of the first kinematic axis should always be zero as it is not possible to measure using opposing probes.

Laser Measurement

The laser measurement option allows collection of errors from an external source such as a laser or electronic level. The measurement can be scale, straightness, or angular when running in data collection mode or scale when running in 10360-2 mode. An example of the laser interface is shown in illustration 33.

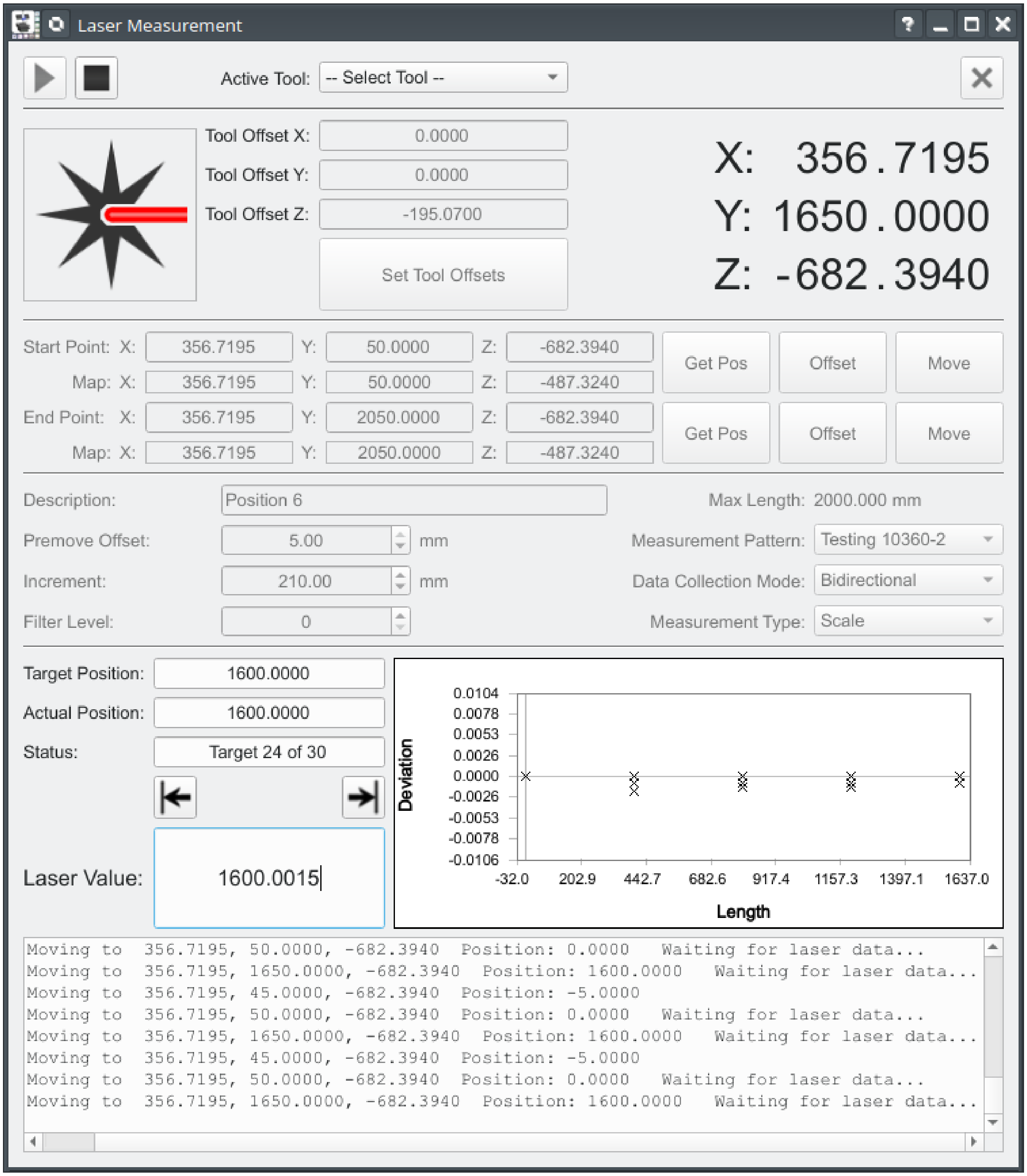
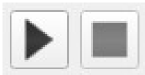
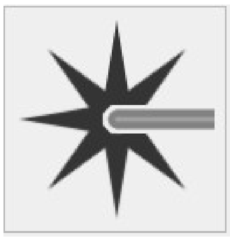
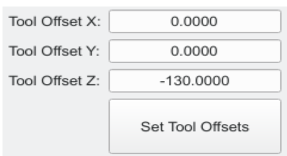
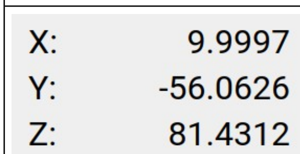


Illustration 33: Laser interface.

Table 31: Laser Options:

Item or Option	*Description*
	Buttons to start or stop the selected measurement type.
Active Tool	Selection for tool to perform the measurement.
	Close button. Functionally identical to using the close button at the top of the window.
	Icon representing the currently active state of the laser. When collecting data the central part of the image will glow red.
	The offset of the active tool or the manually entered tool offset. Clicking the Set Tool Offsets button will override the offsets of the current sensor or set the offsets directly in the controller (depends on controller type). *Note: For I++ clients a tool must be selected in order to set the offsets. The offsets must be cleared in the UCC Server in order to restore the machine to normal function following a manual change to the tool offsets.*
	Coordinate display.
Start Point	XYZ location of the starting position of the measurement.
Start Point - Map	XYZ location of the starting position of the measurement. This value is identical to the Start Point minus the active tool offset.
End Point	XYZ location of the ending position of the measurement.
End Point - Map	XYZ location of the ending position of the measurement. This value is identical to the End Point minus the active tool offset.
Get Pos	Get the current position of the machine. This applies to either the start or end point.
Offset	Move the machine by a small distance in the XYZ direction or adjust the start and end points for a specific measurement length. *The offset option next to the start point allows shifting the XYZ position of the start and end points by a distance up to 5 mm at a time.* *The offset option next to the end point allows the adjustment of the measurement length only.*

Item or Option	*Description*
Move	Drive the machine to the specified coordinates.
Description	Unique description of the measurement. This is stored inside the output file and becomes part of the file name.
Premove Offset	The distance moved when reversing direction. This move is performed prior to a move to the start point or prior to the first reverse direction move at the end point.
Increment	Incremental move distance the machine will move between the start and end points when collecting data.
Filter Level	Value representing the amount of filtering to apply to the machine position. The filtering is weighted with the newest location data given the highest priority.
Max Length	The distance between the start and end point. The real measurement length will not be greater than this value.
Measurement Pattern	Can be set to 10360-2 or Data Collection. Data Collection will allow measurement of scale, straightness, or angular errors where 10360-2 will run the machine through a specific measurement pattern only looking at the scale error.
Data Collection Mode	When the Measurement Pattern is Data Collection this setting can be unidirectional or bidirectional. The second set of measurements when running bidirectional measurements starts at the end position instead of the start position.
Measurement Type	Specifies if it a measurement of scale, straightness, or angular data.
Target Position	Nominal position of the machine relative to the start point and in the direction defined by the start and end points.
Actual Position	Real position of the machine relative to the start point and in the direction defined by the start and end points.
Status	When running in Data Collection mode this will show the direction of measurement and when running in 10360-2 mode this will show the current measurement sample relative to the total measurement count.
Laser Value	Input from the laser. Data is manually input into this field for each measurement position.

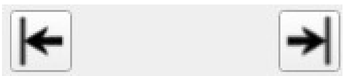
Measurement Entry

The measurement data is entered manually in the *Laser Value* field when running a measurement sequence. When data is entered and the *Return* or *Enter* key on the keyboard is pressed the machine will automatically be driven to the next target point and the previous entry will be automatically selected in anticipation it will be replaced with a new value. The manual entry option is intended to require the minimum steps needed from the operator to enter data and move the CMM to the next target.

Data entry is always manual using the Laser Measurement option in MeasureDirect. Automated data collection is better suited using utilities designed for this purpose.

Next And Previous Move

The Next and Previous buttons allow stepping the machine between measurement targets allowing revisions to the input data. The previously entered data is shown graphically and not in the Laser Value field.



The scenario this addresses is manual entry errors. It is possible to move through the range of the measurement and replace any entered measurement with a new value. Existing values are not replaced unless a new value is entered.

Graph Data

Collected data is displayed graphically in order to provide feedback to the user for error trends and possible entry errors. Illustration 34 shows an example of the graph data from a measurement of the scale.

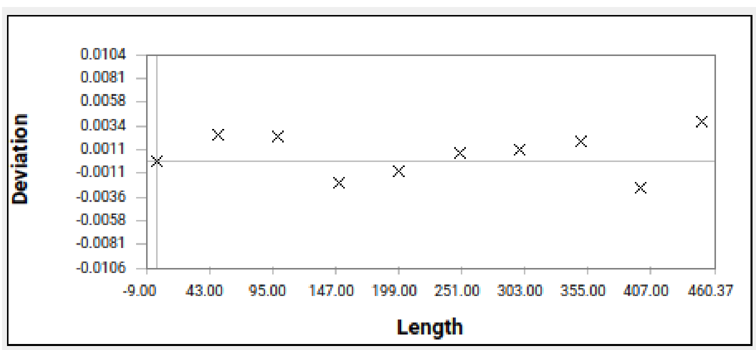


Illustration 34: Graph data from a measurement.

Data Processing

The input data is processed taking into account the real position of the machine for all linear measurements. All data is zero offset when collection is complete. Straightness data has the error slope removed during data collection.

The sign of the error is based on the machine position as compared to the laser where the laser is considered to be the nominal position. This convention is reversed from how most people deal with laser data but it solves a number of problems such as the treatment of deviations from a laser as compared to a physical artifact such as a step gauge.

The following shows examples of measurements on a machine and the expected deviation result.

Table 32: Scale measurement in Y Axis:

Machine (Moving in Y)			*Entered Laser Value*	*Deviation*	*Comment*
X	*Y*	*Z*			
100.000	50.000	-250.000	0.000	0.000	Start
100.000	150.000	-250.000	100.000	0.000	Step increment is 100 mm.
100.000	250.010	-250.000	200.010	0.000	Laser and machine deviation same

Machine (Moving in Y)			Entered Laser Value	Deviation	Comment
X	Y	Z			
100.000	350.000	-250.000	300.010	-0.010	Machine position short
100.000	450.010	-250.000	400.000	0.010	Machine position long

Table 33: Straightness measurement in X while moving Y:

Machine (Moving in Y)			Entered Laser Value	Deviation Note 1	Comment
X	Y	Z			
100.000	50.000	-250.000	0.000	0.000	Start
100.000	150.000	-250.000	0.000	0.000	Step increment is 100 mm.
100.010	250.000	-250.000	0.010	0.000	Laser and machine deviation same
100.000	350.000	-250.000	0.010	-0.010	Machine position short
100.010	450.000	-250.000	0.000	0.010	Machine position long

Note 1: Deviations shown prior to slope removal.

Table 34: Straightness measurement in Z axis while moving the Y:

Machine (Moving in Y)			Entered Laser Value	Deviation	Comment
X	Y	Z			
100.000	50.000	-250.000	0.000	0.000	Start
100.000	150.000	-250.010	0.005	0.000	Deviation zero after slope removal
100.000	250.000	-250.020	0.010	0.000	Deviation zero after slope removal
100.000	350.000	-250.030	0.015	0.000	Deviation zero after slope removal
100.000	450.000	-250.040	0.020	0.000	Deviation zero after slope removal

Table 35: Angular measurement while moving the Y with non-zero starting value:

Machine (Moving in Y)			Entered Laser Value	Deviation	Comment
X	Y	Z			
100.000	50.000	-250.000	0.100	0.000	Start
100.000	150.000	-250.000	0.100	0.000	Deviation zero after offset removal
100.000	250.000	-250.000	0.100	0.000	Deviation zero after offset removal
100.000	350.000	-250.000	0.100	0.000	Deviation zero after offset removal
100.000	450.000	-250.000	0.100	0.000	Deviation zero after offset removal

I++ Interface – Infinite Tool Heads

When using the I++ interface on machines with non-locking heads such as a PH20 or REVO the random offset of the head will affect the real position of the machine to the point where data collection is not possible unless the head is disabled. Machines equipped with analogue tools such as a SP25 on a locking tool head such as a PH10M can be setup with a more traditional touch trigger tool where this is not possible with a PH20 or REVO head.

Temperature Compensation

Temperature compensation can be configured for manual or automatic in *MeasureDirect*. Temperature compensation is only available for the measurement of step gauges, gauge blocks, and ball bars unless it is always active in the controller.

Temperature compensation is handled by *MeasureDirect* unless the machine is using temperature compensation that cannot be disabled (see *Controller Thermal Mode* for details). Most controllers are capable of performing temperature compensation but, for simplicity, it was decided to handle this feature inside *MeasureDirect*. Machines with permanently active temperature compensation are typical for shop floor model CMM's.

The following table shows the behaviour of *MeasureDirect* with various options related to temperature compensation:

Table 36: Temperature Compensation Options:

Controller Thermal Mode	*Enable Temperature Compensation Checked*	*Temperature Sensor Identification*	*Comment*
Compensation Not Active	NO	<ignored>	All input fields are active. Temperatures and other entries are stored with the measurement data but no corrections are performed.
Compensation Not Active	YES	-1	Temperature compensation is active. The temperature for the entry must be manually input before starting the measurement.
Compensation Not Active	YES	<non-negative value>	Temperature compensation is active. The temperature for the entry is automatically read from the controller before starting the measurement.
Compensation Always Active	<always checked>	-1	Temperature compensation of the axis is active in the controller. The temperature for the entry must be manually input before starting the measurement. The correction of the part is done by the controller or *MeasureDirect* depending on the interface.
Compensation Always Active	<always checked>	<non-negative value>	Temperature compensation of the axis is active in the controller. The temperature is automatically read from the controller before starting the measurement. The compensation of the part is done by the controller or *MeasureDirect* depending on the interface.

Temperatures are read at start of the measurement cycle and not during the measurement. If there are changes in temperature during the execution of a measurement routine that have an impact on the results no further measurements should be done until the machine and artifacts has had sufficient time to acclimate.

Output, Reporting, and Validation

The output, reporting, and validation section handles the destination of measurement files and viewing results from the various measurements performed. The validation option allows test data to be generated in order to verify the best-fit functions of *MeasureDirect*.

Output Settings

Results from the various measurements are written to a file. The location where the output files are created is defined by the *Output Settings* dialog.

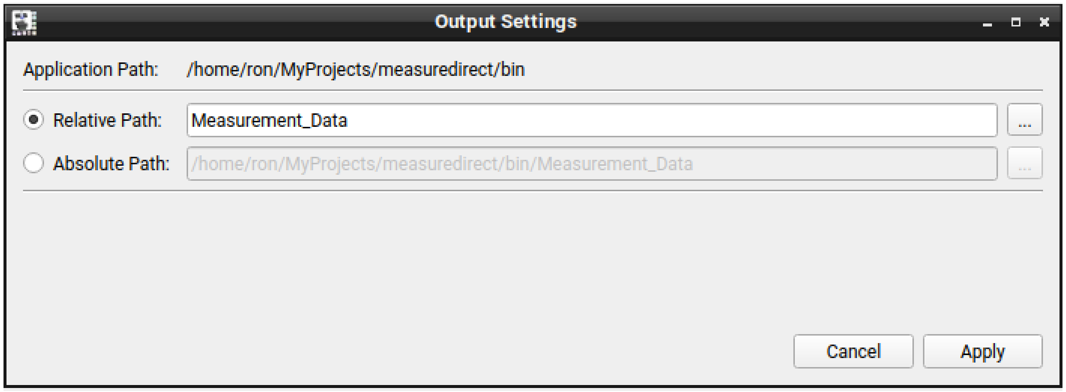


Illustration 35: Output Settings.

Table 37: Output Options:

Option	*Description*
Relative Path	Output files are written to a named subdirectory using the current location of the executable as the first part of the output path.
Absolute Path	Output files are written to a specific path.

Best Fit Validation

The various measurements performed by *MeasureDirect* involve the measurement of features such as lines, planes, spheres, and circles. Due to the nature of this utility it is not practical to have the best-fit routines independently tested by organizations such as PTB or NIST. To allow verification of the fitting routines by the end user a utility was added that can generate random test data in a manor similar to how PTB or NIST would perform this kind of test. The test data contains calculated results from the point data and those points can be imported into software that is either PTB or NIST approved in order to perform a comparison.

In the early days of CMM's the best-fitting routines used by the different manufacturers would often produce results that differed by more than an acceptable amount. The reasons for this are assumed to be a combination of computer limitations and improper assumptions made by the fitting routines. Regardless of the reason it was common enough that standard testing was introduced in order to verify the math used by the inspection software.

The testing performed by PTB or NIST is very narrow where it only focuses on standard geometry such as circle, cone, sphere, plane, line, and cylinder. Features such as a round or square slot are not tested and the results provided is at the discretion of the software provider. The testing performed by PTB or NIST does not extend beyond best-fitting of the listed features and does not include secondary information such as form error.

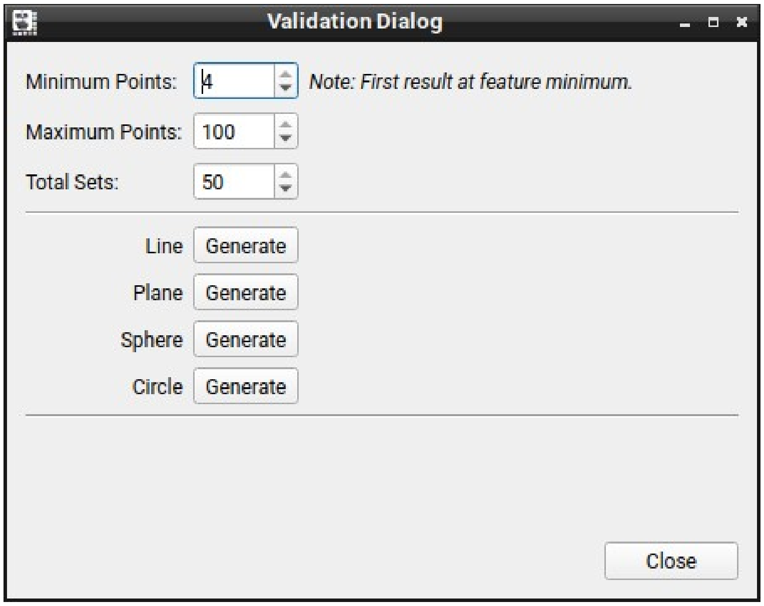


Illustration 36: Best fit validation test data generator.

Table 38: Best Fit Validation Options:

Option	*Description*
Minimum Points	The minimum number of points to generate for each feature type.
Maximum Points	The maximum number of points to generate for each feature type.
Total Sets	The number of test sets to create.
Generate	Create the test data associated with the selected feature.
Close	Close the dialog.

The first generated result, regardless of the minimum points setting, is always at the feature minimum. The minimum is two points for a line, three for a circle and plane, and four for a sphere.

The output file id number starts at the set number and decrements to one. This was done to make it easier to process the file (last set of results always has an id of 1).

Validation Procedure

The validation is done by comparing against software that is currently PTB or NIST approved. The validation utility generates a set of features and all related points that must be imported into the reference software in order to perform this comparison.

An example of data generated by the validation routine for a plane and circle is shown below:

```
...
Plane   29   8   687.425186   -474.935934   745.279081   -0.668350684   0.395151957
```

```
0.630208135 0.086011
  681.343746 -510.702534 761.301299
  705.413802 -464.574712 757.913522
  692.259639 -439.391299 728.114340
  667.505521 -457.607274 713.316396
  687.530358 -491.021494 755.408119
  691.163932 -455.063784 736.737592
  687.512786 -487.248897 753.156801
  686.671707 -493.877478 756.284577
...
Circle  20  4  1108.205211  -144.321467  602.143775  0.000000000  0.000000000
1.000000000 99.851859 0.011620
  1058.488415 -139.766724 602.143775
  1083.675236 -100.830229 602.143775
  1087.044617 -99.107792 602.143775
  1069.888216 -176.328367 602.143775
```

Format:

```
Plane <id> <point_count> <X> <Y> <Z> <I> <J> <K> <form_error>
Circle <id> <point_count> <X> <Y> <Z> <I> <J> <K> <diameter> <form_error>
Line <id> <point_count> <X> <Y> <Z> <I> <J> <K> <form_error>
Sphere <id> <point_count> <X> <Y> <Z> <diameter> <form_error>
```

Where:

```
id = Unique identification of the feature.  The id number ends at 1
point_count = Number of data points used for the calculated feature.
XYZ = Position of the feature.
IJK = Orientation of the feature.  For circles it is the projection plane.
diameter = Diameter of feature with size.
form_error = Form error of the feature.
```

The format of the data file use a space as the delimiter for the data. This was chosen in order to make it easier for software such as Tutor for Windows to read the data files directly.

Plane, Line Validation

The point produced by the best fit plane or line is usually central to the defining points but this is not always the case. To validate the position data the distance between the points either parallel or perpendicular to the feature axis must be done to ensure the results are correct.

Plane:

$$Deviation = (P1.x - P2.x) * I + (P1.y - P2.y) * J + (P1.z - P2.z) * K$$

Line:

$$Deviation = Length\,of\,(P1 - P2)\,x\,IJK$$

Validation Program Using Tutor for Windows

The following is an example of a part program written in Tutor for Windows that will load the plane test data and generate a set of results that can be used to compare with the fitting routines of *MeasureDirect*. Other feature types are similar:

```
program TESTF[WM1,WM2]
  element_array MEMORY[300]
!
  string TEXT[5]
  string LINE[80]
  real X,Y,Z,I,J,K,F
  integer ID,COUNT
  vector POS,VEC
!
  format (plane,x=meas,y=meas,z=meas,cx=meas,cy=meas,cz=meas,f=meas)
!
  openf (f0,"c:\wtutor\data\bfplane.dat")
  reset (f0)
!
  openf (f1,"c:\wtutor\data\result.dat")
  rewrite (f1)
!
! Read header
!
  readln (f0,LINE)
!
  TOP:
  readln (f0,TEXT,ID,COUNT,X,Y,Z,I,J,K,F)
!
  for CNTR=1 to COUNT by 1
    readln (f0,X,Y,Z)
    define_element (MEMORY[9+CNTR],pick,x=X,y=Y,z=Z)
  end_for
!
  ipl (MEMORY[1],COUNT,MEMORY[10])
  delay (1)
!
  POS=MEMORY[1]
  getdir (MEMORY[1],VEC)
  F=MEMORY[1]|f
   writeln (f1,POS|x:12:6," ",POS|y:12:6," ",POS|z:12:6," ",VEC|x:12:9," ",VEC|
y:12:9," ",VEC|z:12:9," ",F:12:6)
!
  if ID ne 1 then
    jump TOP
  end_if
!
  closef (f0)
  closef (f1)
!
endstat
end_program
```

Following the execution of this program a file called *Result.dat* is created containing the position, vector, and form from the different sets of points contained in the source file.

Line Validation Example Using PC-DMIS

Writing a part program in PC-DMIS to load and generate features from the test data is difficult (maybe impossible) so no sample program is shown. The point data can be converted into a format such as an XYZ file then imported into PC-DMIS which seems to be the best option.

The following is an example of a 34 point line comparison selected at random:

	X	Y	Z	I	J	K	Form
MeasureDirect	-665.067067	-603.507172	-349.591716	-0.267234877	0.920494914	0.285087063	0.121951
PC-DMIS	-678.42881	-557.48242	-335.33736	-0.2672349	0.9204949	0.2850871	0.12195

Position:

P1-P2	-13.361743	46.024752	14.254356
Cross Product	-0.000001	-0.000001	0.000002
Length	0.000003		

Vector:

V1 – V2	-0.000000023	-0.000000014	0.000000037

Form:

F1 – F2	0.000001

The position of the resulting line between the two software is different so, for proper comparison, it is necessary to find the distance of the compared result to the position and axis of the reference line.

The maximum display resolution of coordinates is 5 decimal places for PC-DMIS. All coordinate deviations show differences at the 6th decimal place as a result. The maximum display resolution of vectors is 7 decimal places for PC-DMIS. All vector deviations show differences at the 8th decimal place as a result.

MeasureView

The data files created by *MeasureDirect* can be displayed using the *MeasureView* utility. *MeasureView* is a stand alone utility that can be opened by clicking of the *Measurement Report* icon of *MeasureDirect* or by opening the *MeasureView* executable directly. Illustration 37 shows the *MeasureView* utility.

The *MeasureView* utility has four utility functions:

- Step Gauge Nominal Editor.
- Measurement Data manager.
- Text measurement results.
- Graphical measurement results.

The nominal editor and measurement manager are dockable widgets that can be separated from the main window, moved to either side, or hidden. Widgets that are hidden can be restored from the *View* menu of *MeasureView*.

The toolbar area of the *MeasureView* utility has three options; tolerance, point display mode, and line display mode. The point and line display modes affect the view of step gauge data.

Step gauge measurements can only be viewed if nominal data exists for the gauge. The *displayed data is automatically corrected using the nominal data.*

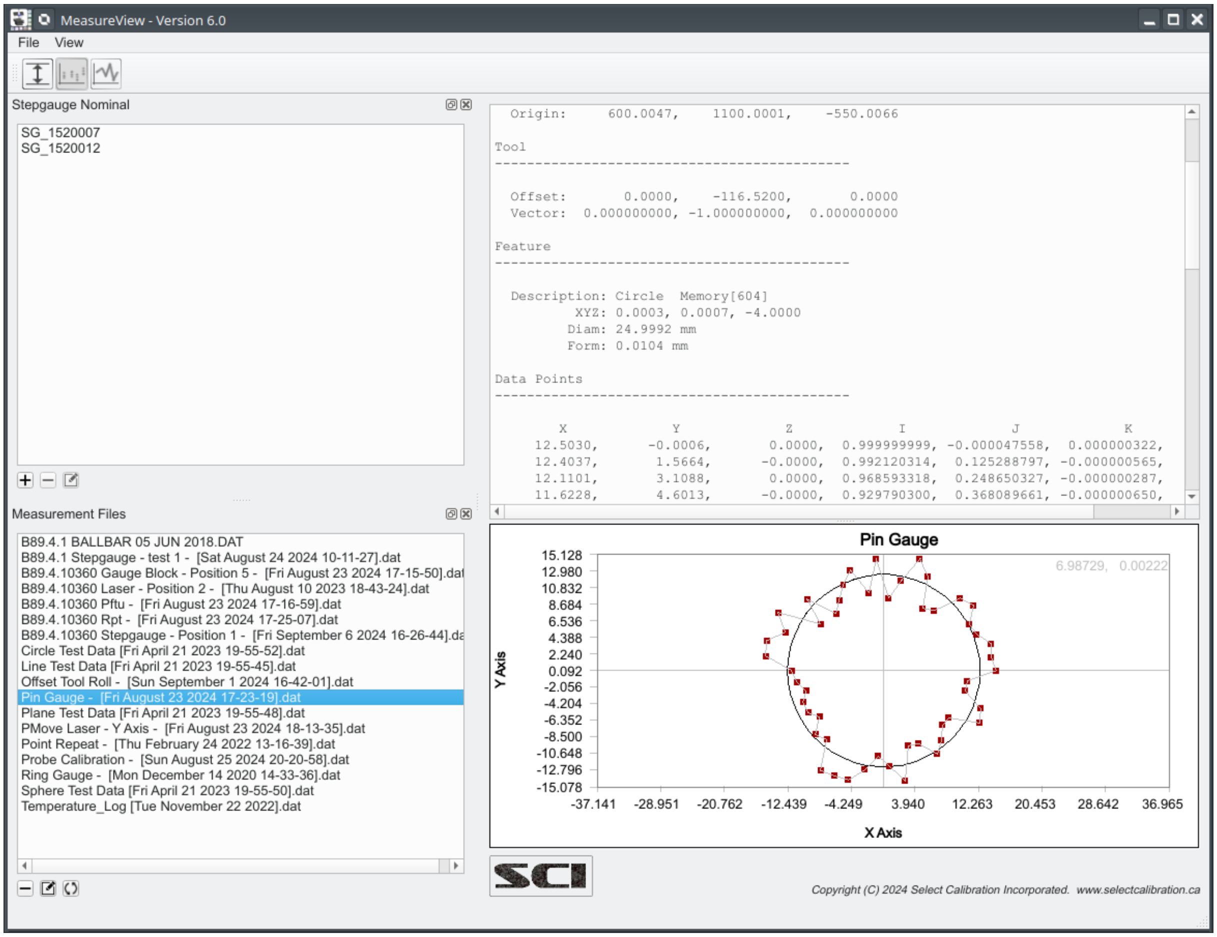


Illustration 37: MeasureView utility showing results from a pin gauge measurement.

Step Gauge Nominal Editor

The step gauge nominal editor allows creation of the nominal data for step gauge or ballbar 10360 measurements. Clicking on the add or edit button will open the step gauge nominal editor as shown in illustration 38.

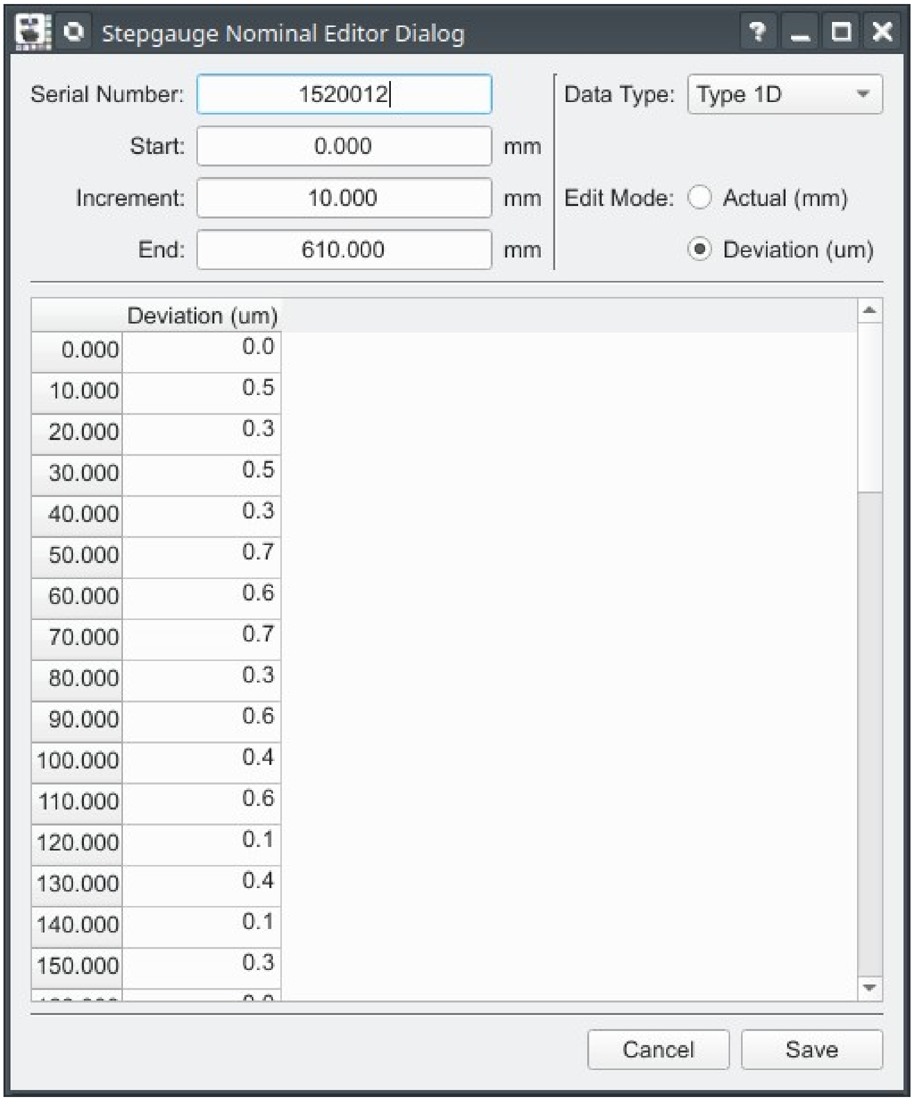


Illustration 38: Step gauge nominal editor in 1D mode configured to show deviations only.

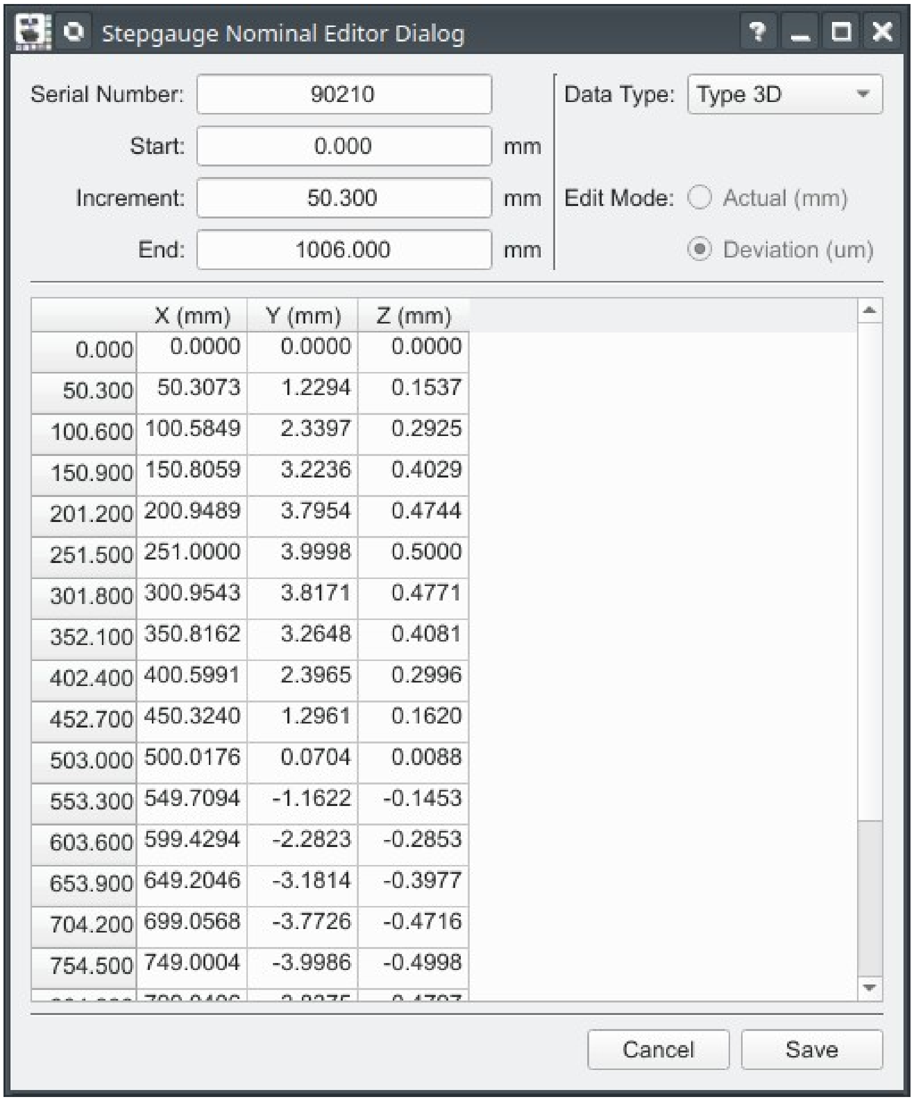


Illustration 39: Step gauge nominal editor in 3D mode showing nominal XYZ positions.

To create new step gauge nominal data enter the nominal increment and end position of the gauge. Once configured choose a suitable editing mode and enter the known values of the gauge in the fields provided.

Table 39: Nominal Editor Options:

Option	*Description*
Data Type	Can be set to either Type 1D or Type 3D. The 1D type is suitable for gauge block types of gauges where the 3D option is suitable for features such as spheres mounted on a bar.
Actual	The data entries is the actual measured step positions without a nominal value. The actual positions are in millimetres.

Option	*Description*
Deviation	The data entries is the deviation from the nominal step position. The deviation values are in micrometers.

Data can be entered into the table using standard clipboard functions.

Ballbar 10360 Artifact Calibration

The data used for ballbar 10360 artifacts is the nominal location of each sphere along the length of the artifact relative to the first sphere. The requirements for MeasureView is that the measurements are from a standard right-hand coordinate system with the positive X along the length of the artifact.

The reported measurements are lengths between the spheres with the nominal values calculated from the distances between the nominal sphere locations from the calibration data. The nominal lengths are the 3D distances between the nominal locations of the measured spheres and determined when the report is created. Unlike a typical 1D gauge this creates a unique set of problems that must be dealt with properly. Illustration 40 shows an example of a calibration file and subsequent measurement results.

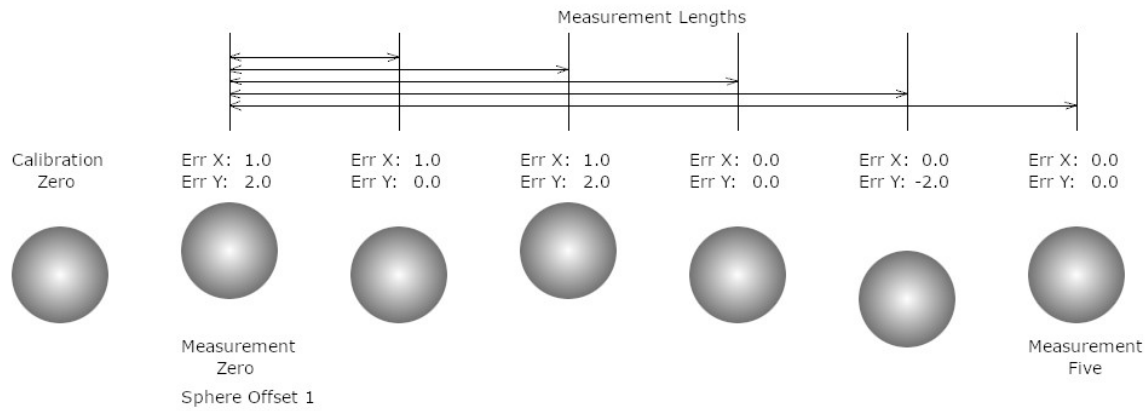


Illustration 40: Example 3D calibration data for a ballbar 10360 measurement.

Table 40: Calibration Data:

Sphere Offset	*Calibration Data X (mm)*	*Calibration Data Y (mm)*	*Calibration Data Z (mm)*
0	0.0000	0.0000	0.0000
1	101.0000	2.0000	0.0000
2	201.0000	0.0000	0.0000
3	301.0000	2.0000	0.0000
4	400.0000	0.0000	0.0000
5	500.0000	-2.0000	0.0000
6	600.0000	0.0000	0.0000

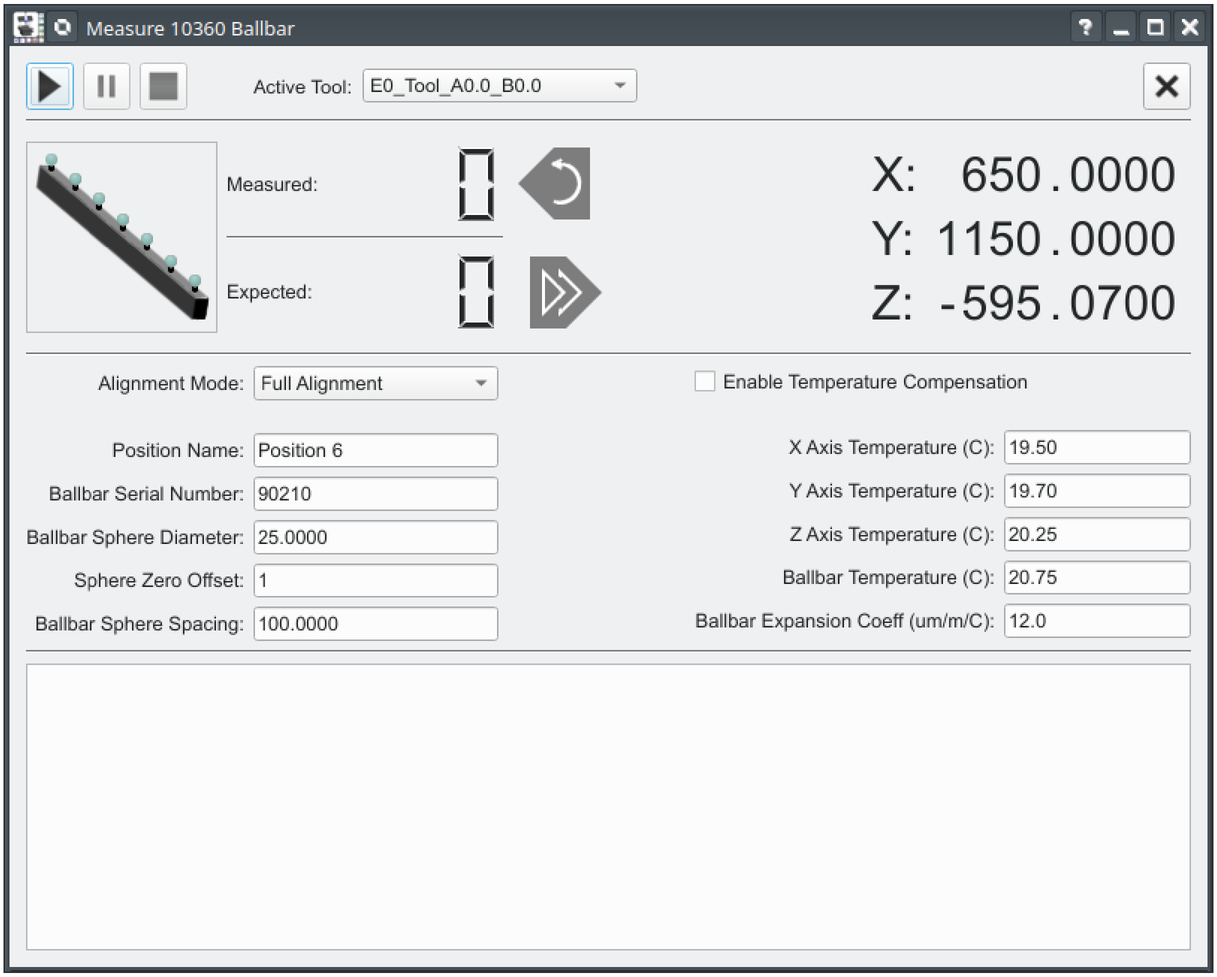


Illustration 41: Measurement of ballbar 10360 using MeasureDirect.

Intermediate measurement results from MeasureDirect:

Name	X	Y	Z	D	F
Memory[504]	600.0000	850.0000	-497.5000	25.0000	0.0000
Memory[505]	600.0000	950.0000	-497.5000	25.0000	0.0000
Sphx-Sph0	100.0000				
Memory[506]	600.0000	850.0000	-497.5000	25.0000	0.0000
Memory[507]	600.0000	950.0000	-497.5000	25.0000	0.0000
Sphx-Sph0	100.0000				
Memory[508]	600.0000	850.0000	-497.5000	25.0000	0.0000
Memory[509]	600.0000	950.0000	-497.5000	25.0000	0.0000
Sphx-Sph0	100.0000				
Memory[510]	600.0000	850.0000	-497.5000	25.0000	0.0000
Memory[511]	600.0000	1050.0000	-497.5000	25.0000	0.0000
Sphx-Sph0	200.0000				
Memory[512]	600.0000	850.0000	-497.5000	25.0000	0.0000
Memory[513]	600.0000	1050.0000	-497.5000	25.0000	0.0000
Sphx-Sph0	200.0000				

```
Memory[514]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[515]     600.0000  1050.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       200.0000
Memory[516]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[517]     600.0000  1150.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       300.0000
Memory[518]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[519]     600.0000  1150.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       300.0000
Memory[520]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[521]     600.0000  1150.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       300.0000
Memory[522]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[523]     600.0000  1250.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       400.0000
Memory[524]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[525]     600.0000  1250.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       400.0000
Memory[526]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[527]     600.0000  1250.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       400.0000
Memory[528]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[529]     600.0000  1350.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       500.0000
Memory[530]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[531]     600.0000  1350.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       500.0000
Memory[532]     600.0000   850.0000  -497.5000    25.0000      0.0000
Memory[533]     600.0000  1350.0000  -497.5000    25.0000      0.0000
Sphx-Sph0       500.0000
INF:  Sequence Complete.
```

Results after processing by MeasureView using the nominal data listed above:

```
Measurement Lengths mm
--------------------------------------------

     Nominal       Actual      Deviation

    100.0200     100.0000       -0.0200
    100.0200     100.0000       -0.0200
    100.0200     100.0000       -0.0200
    200.0000     200.0000        0.0000
    200.0000     200.0000        0.0000
    200.0000     200.0000        0.0000
    299.0067     300.0000        0.9933
    299.0067     300.0000        0.9933
    299.0067     300.0000        0.9933
    399.0200     400.0000        0.9800
    399.0200     400.0000        0.9800
    399.0200     400.0000        0.9800
    499.0040     500.0000        0.9960
    499.0040     500.0000        0.9960
    499.0040     500.0000        0.9960
```

Comments:

- Nominal length from sphere 1 to sphere 2 is 100.020 mm. This is from a deviation in the Y axis of 2 mm over a length of 100 mm which results in an increased nominal length of 0.02 mm.
- Nominal length from sphere 1 to sphere 3 is 100.000 mm. Although both spheres have errors in their positions relative to the zero sphere the errors are identical for both and cancel out.
- Nominal length from sphere 1 to sphere 4 and 6 are different even though the sphere position error is always 2 mm. The distance between each pair of spheres relative to the offset is why this value changes as the length increases.
- The nominal length from sphere 1 to sphere 5 has a relative error of 4 mm between the two spheres unlike the other examples where the relative Y error is either zero or 2 mm.
- There doesn't appear to be a method to handle this kind of measurement without using a 3D nominal error map of the artifact. Any method that tries to adopt existing 1D methods to this kind of artifact will probably be wrong unless limits are set on the specific spheres measured for any given position.

Measurement Manager

The measurement data files are listed by the measurement manager. Selection of any measurement file will display the data. The list of measurement files is automatically updated when changes to the data directory are detected or the refresh button is clicked.

Removing Measurement Files

Measurement files that are no longer needed can be removed by clicking on the remove (-) button. Measurement files are not deleted but simply moved to a subfolder called *old*.

Input Settings

The input settings defines the location where the measurement data exists from the *MeasureDirect* utility. The default setting is to use the same relative path as *MeasureDirect*.

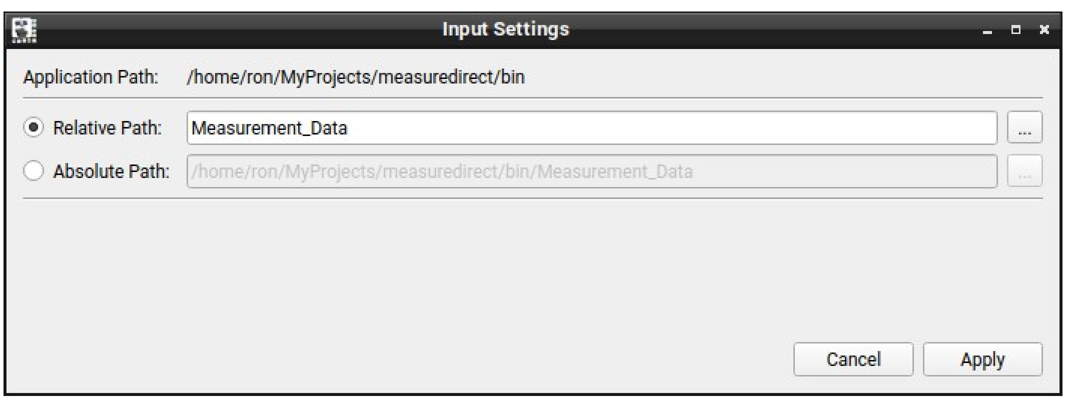


Illustration 42: Measurement Input Settings.

Table 41: Input Options:

Option	*Description*
Relative Path	Input files are read from a named subdirectory using the current location of the executable as the first part of the input path.
Absolute Path	Input files are read from a specific path.

Specification Editor

The specification editor allows the user to enter a tolerance for step gauge or ballbar measurements. The editor is accessed by clicking on the editor icon from the tool bar. Illustration 43 shows and example of the specification editor.

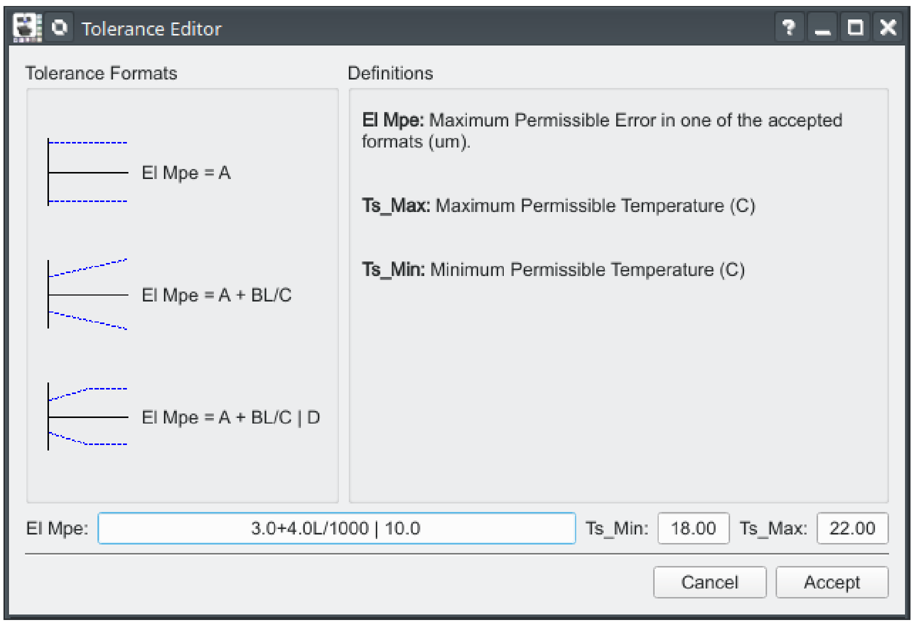


Illustration 43: Specification editor.

Table 42: Specification Editor Formats:

Format	*Description*
Single Value	The tolerance is a fixed value regardless of length.
Expression	The tolerance consists of an initial value and increases based on length.
Expression With Limit	The tolerance consists of an initial value and increases based on length to an upper limit.

The entered specification is a treated as a +/- value for a step gauge and a bandwidth for ball bar measurement.

Measurement Report Samples

The following show samples of some of the data that can be reported by *MeasureView*:

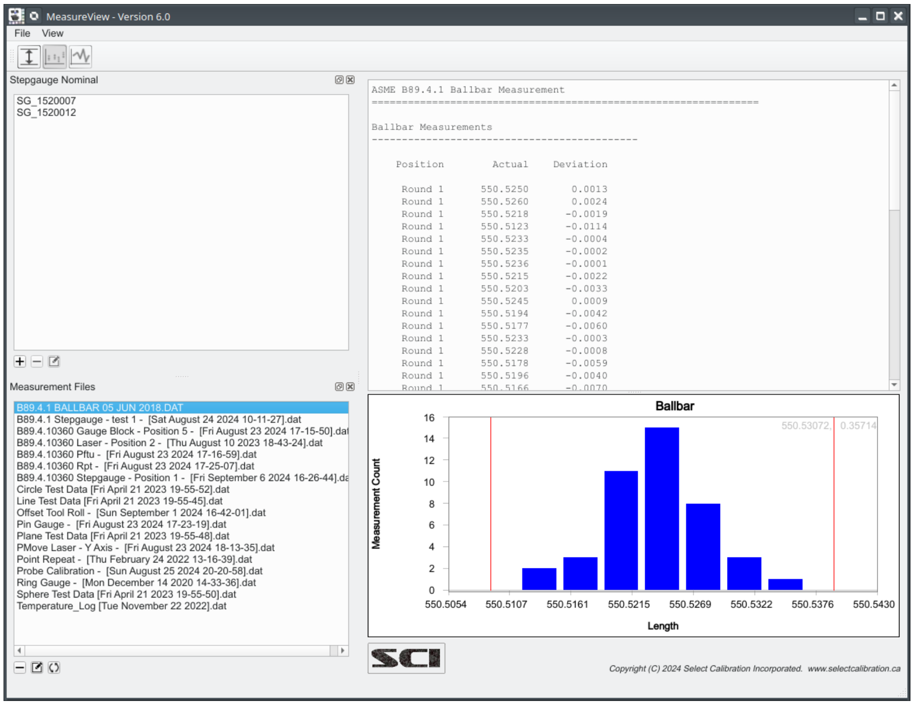


Illustration 44: MeasureView showing the display of ball bar measurement data. Red lines represent the specification limits.

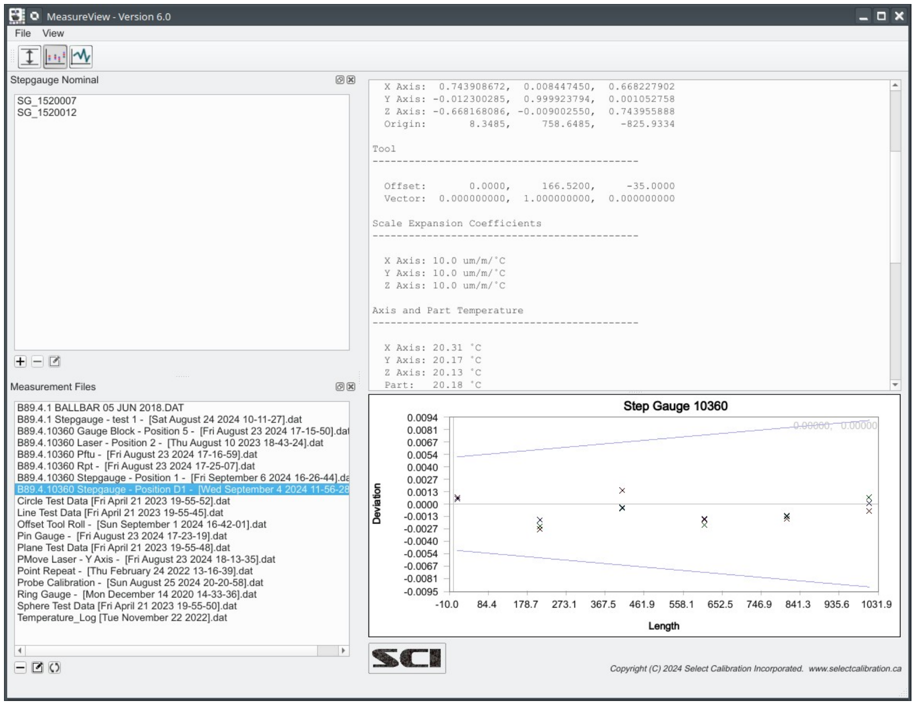


Illustration 45: Stepgauge 10360-2 measurement in point display mode.

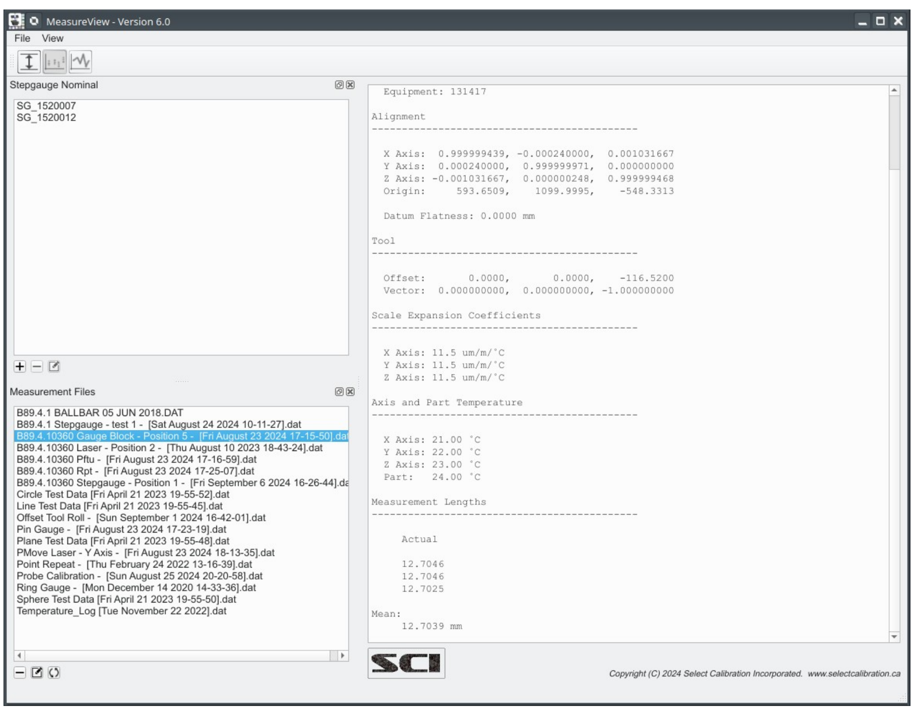


Illustration 46: Gauge block 10360-2 measurement.

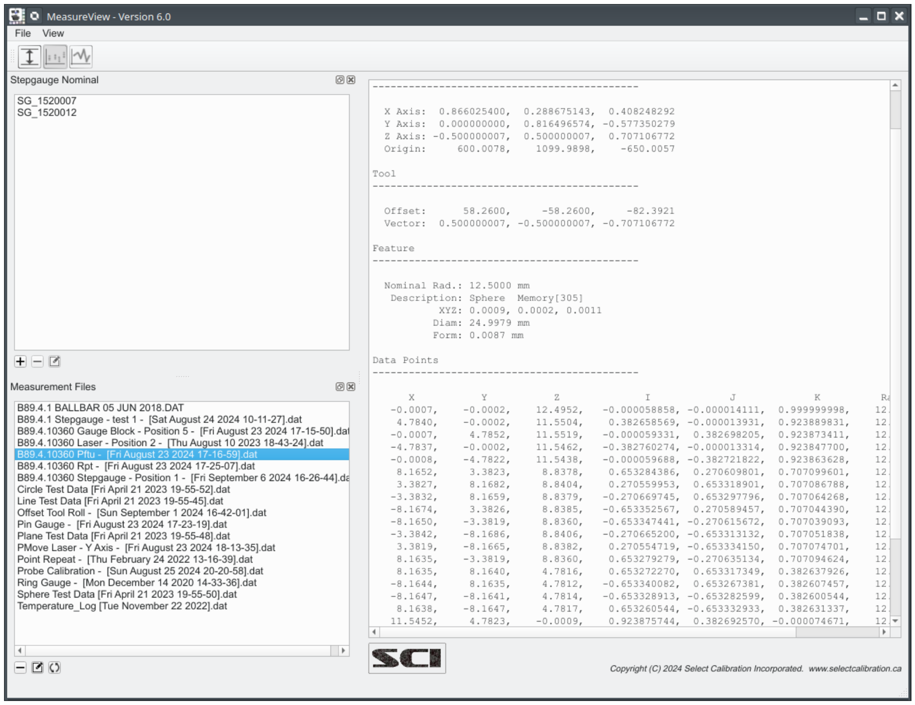


Illustration 47: Sphere Pftu measurement.

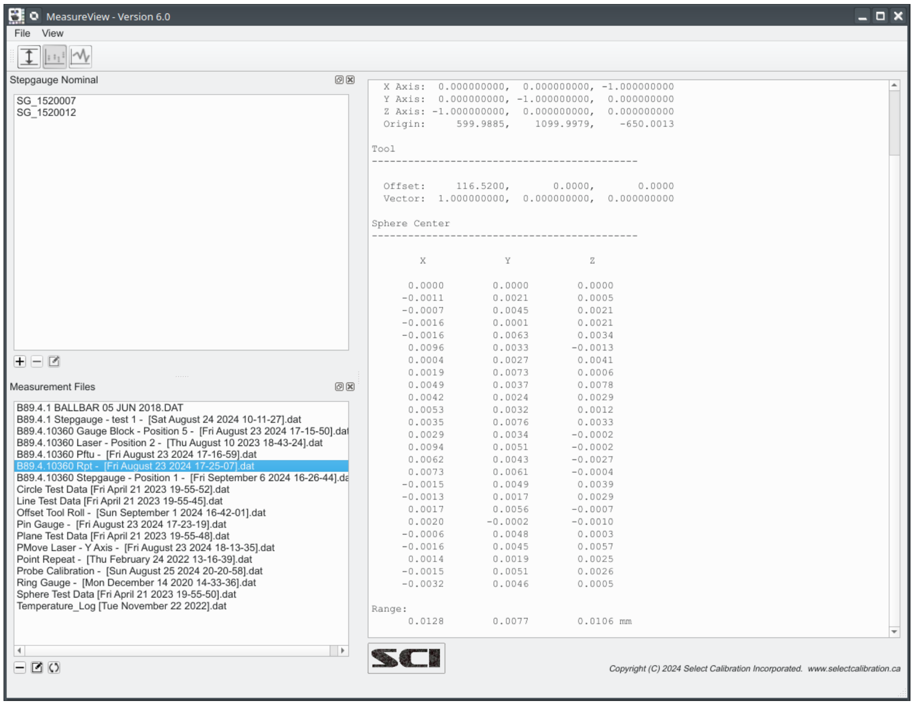


Illustration 48: ASME B89.4.10360-2 Rpt measurement.

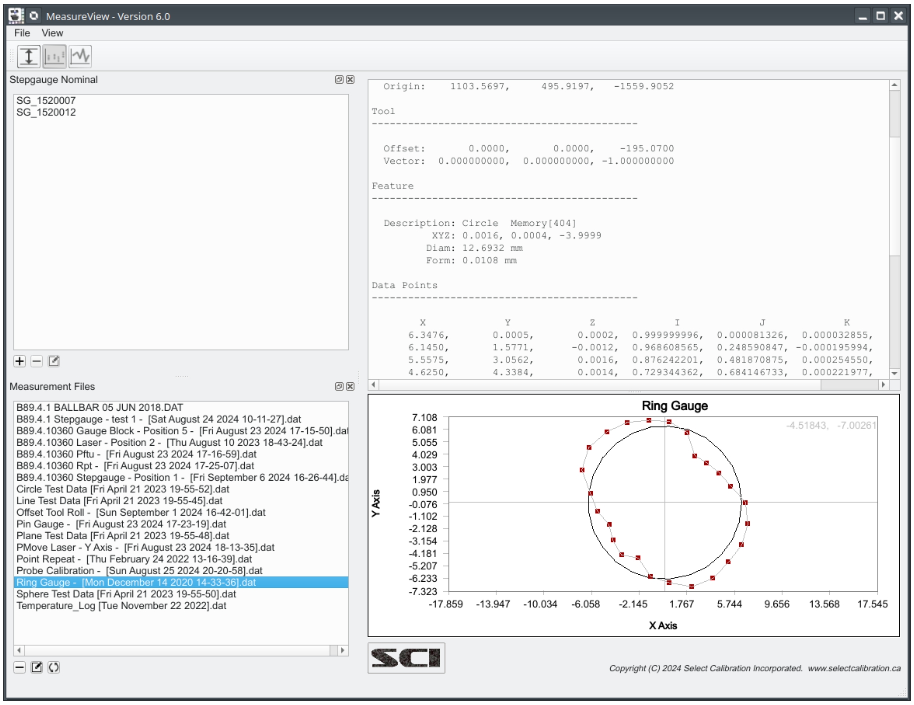


Illustration 49: Ring gauge measurement.

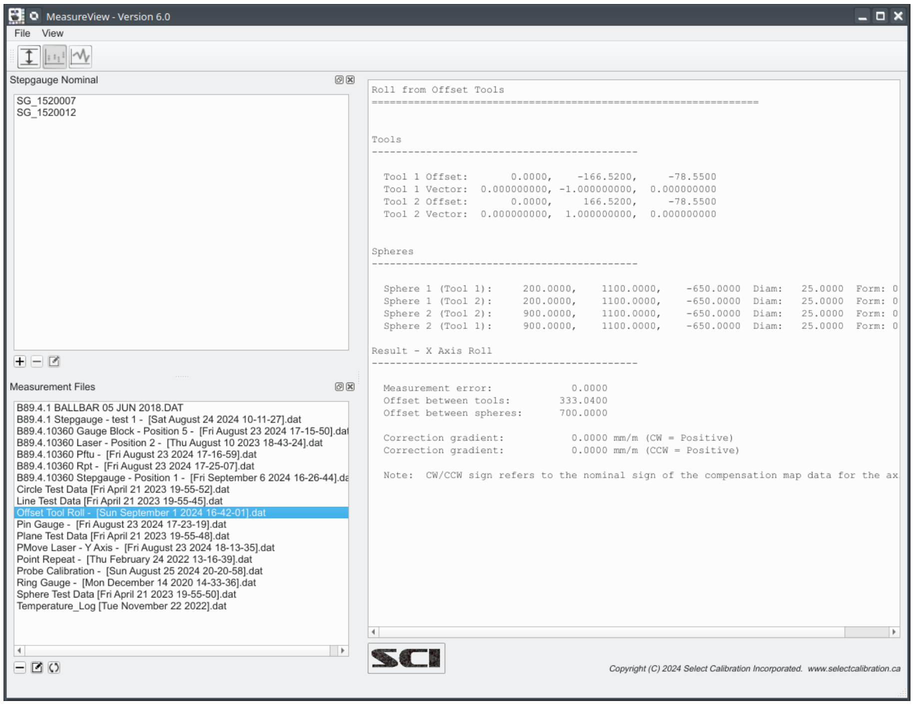


Illustration 50: Roll measurement.

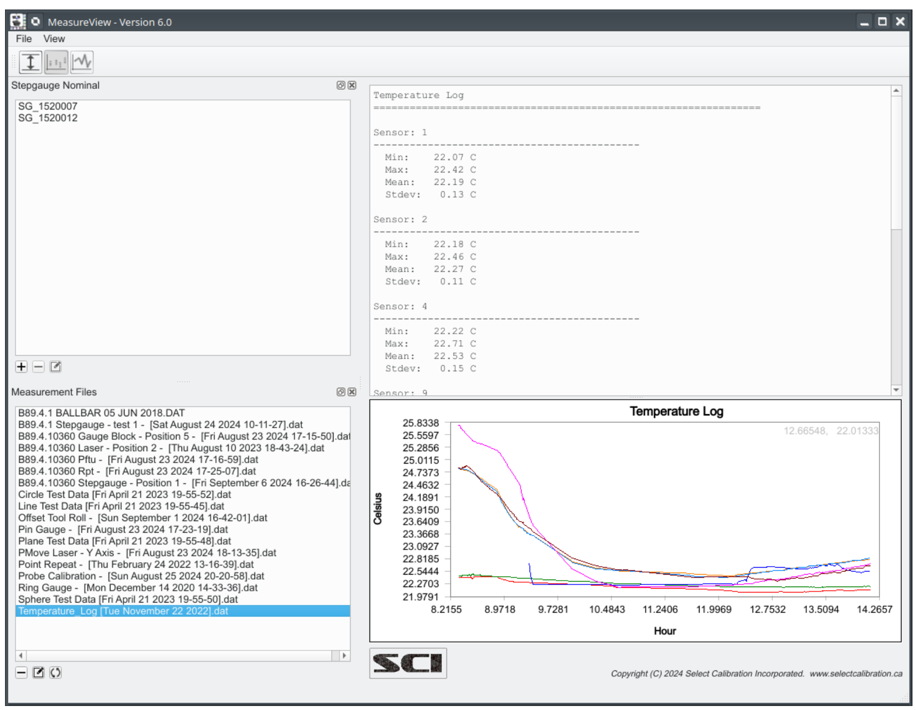


Illustration 51: Display of temperature log data.

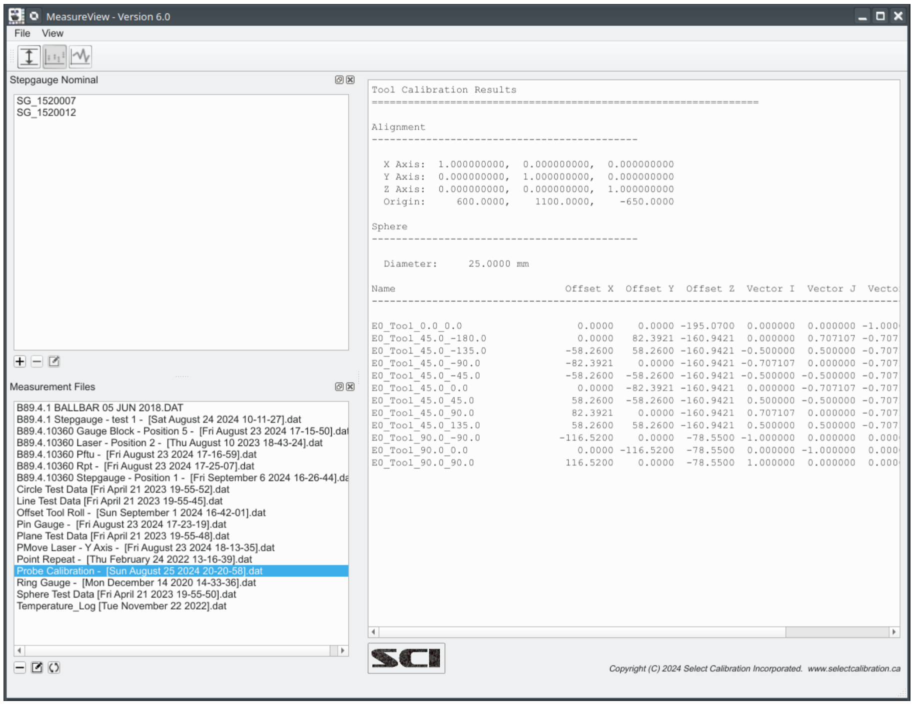


Illustration 52: Probe calibration result display.

Laser Measurement Data

Data from either laser measurement type is displayed graphically and in text. If the measurement type is *Data Collection* the results are sorted and combined into a single value for each target point.

Note: The sign of the error treats the laser as the nominal and the machine as the actual. This convention may be reversed from sign conventions used by the target error compensation map.

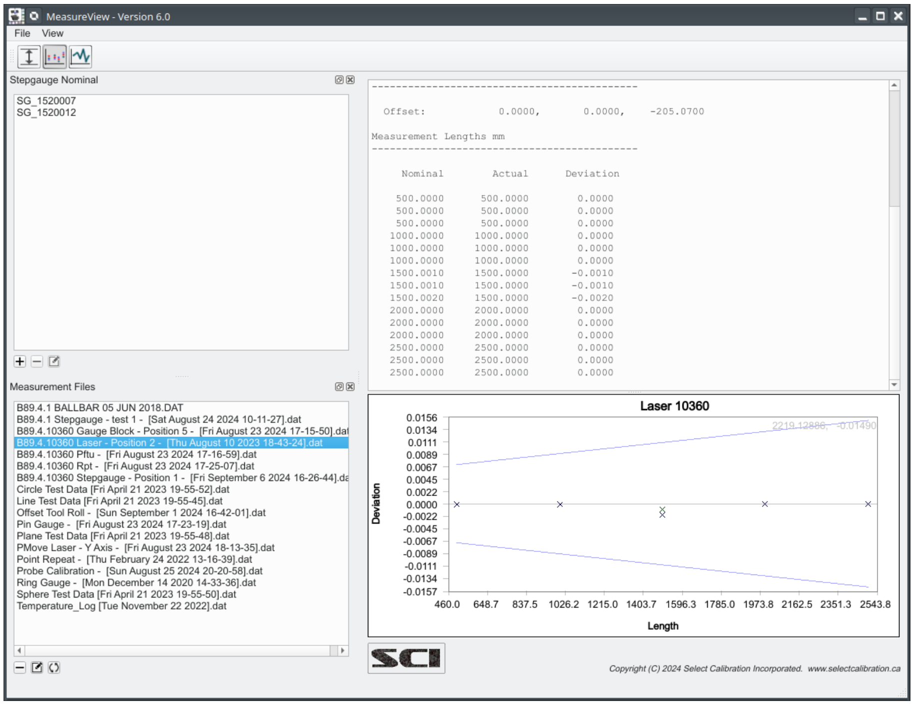


Illustration 53: Laser measurement display from 10360-2 diagonal measurement.

Revision History		
Date	*Version*	*Changes*
July 2020	0.00	Program Development. Alpha mode
Sep 2020	0.01	Initial testing.
Oct 4, 2020	0.10	Rewrite of probe utilities Numerous changes from 0.0x versions
Oct 11, 2020	0.11	Add DC controller driver Probe hits not checked frequently enough. Collision during probe calibration. Send current machine settings at start of any measurement.
Oct 27, 2020	0.12	[bugfix] Probe configuration setting lost when probe utilities opened. Added option to handle controller temperature compensation.
Nov 11, 2020	0.20	[bugfix] No warning when indexing probe in manual mode. [bugfix] Measurement options disabled in simulation mode. Added option for Koba step gauges Updated artifact settings
Nov 15, 2020	0.21	[bugfix] Incorrect clearance move for ballbar Added default manual points for various measurements. Added option to turn on or off the move blending (fly). Revamp of the probe tool data dialog.
Nov 23, 2020	0.22	[bugfix] Output file not opened for sphere repeatability [bugfix] Pingauge diameter not stored in INI file. [bugfix] Nominal pingauge diameter set to ballbar sphere diameter. [bugfix] Pingauge deviation includes probe stylus diameter. [bugfix] Pftu deviation includes probe stylus diameter. [bugfix] Unable to use absolute output file path. [bugfix] Sphere RTP point number always shows 1 in output. [bugfix] Added temperature and CTE for gauge blocks. Added MeasureView utility for viewing data files.
Nov 26, 2020	0.30	[bugfix] Alignment axis in MeasureView text report incorrect. Added option to automatically read sensor ID's. Updated MeasureView for graphical view of ballbar data.
Dec 4, 2020	0.40	[bugfix] Controller generated errors not reset. [bugfix] DC Controller authentication sequence incorrect. [bugfix] Machine parameters not sent prior the probe calibration. [bugfix] Graph data not hidden when errors reported [bugfix] Added serial number to missing step gauge message. Added option to handle jogbox keypress commands from controller. Added severity level to error messages.
Dec 15, 2020	0.41	[bugfix] Last machine settings not used by default. Normalized sphere stem vector input data. Changed sorting for tool angles in probe and measure utilities. Save and restore connection settings for each controller type.

Revision History		
		Moved communication debug option to project file. Changed default colours of MeasureView step gauge results. Changed interpretation of tolerance for ballbar measurements. Reduced multiplier for ring and pin gauge graphical view.
Jan 10, 2021	0.50	[bugfix] Probe head orientation validation label not updating. [bugfix] Active offset configuration not updated with orientation. [bugfix] Communication blocked after stopping sequence. [bugfix] Errors not shown in log. [bugfix] Communication buffer size set too high for Leitz / DC. [bugfix] Abort errors cause endless loop of messages. [bugfix] Queued commands sent following abort. Added display of machine's CTE if temperature compensation active. Added additional move point during probe calibration. Changed default tool names to E0_Tool and E150_Tool Updated add tool angle dialog to show the current angle list.
Feb 28, 2021	1.0	[bugfix] Memory access violation possible from touch points [bugfix] Gauge block part temperature not updated automatically. [bugfix] Gauge block expansion default value is incorrect. [bugfix] Tab order defined by sequence of measurements. [bugfix] Measurement data path may not exist in certain situations. Cleanup of communication commands. Added default probe configurations for TP200. Disable debug options and initial release.
Mar 26, 2021	1.1	[bugfix] Spurious touch causes sequence problems. [bugfix] Move commands for DC and Leitz sent while in manual. Added 'possible error exceeds 0.050 mm' to MeasureView message.
May 12, 2021	1.2	[bugfix] Stepgauge square position name not remembered. Compare controller max speeds and acceleration to user values.
Jun 24, 2021	1.3	Added option to monitor temperature sensors of a CMM. Added Next option following feature measurements.
July 6, 2021	1.4	Added probe builder for probe offset configurations.
July 8, 2021	1.5	Increased nominal search tolerance to 2 mm from 0.05 mm. Added option to display step gauge data as points or lines.
July 13, 2021	1.6	[bugfix] Actual tip diameter not stored in simulation. [bugfix] Report error if tool selected without configuration.
Nov 14, 2021	1.7	[bugfix] Keyboard Enter erases hit instead of activating Next. [bugfix] Improve reset sequence for Leitz and DC controllers. [bugfix] Tool orientation uses default until changed. Added tooltips for various buttons. Changes some of the icons to better reflect function. Increased position update frequency. DC controllers: enabled position updates while running a sequence.
Dec 14, 2021	2.0	[bugfix] Better handling of machine errors and error conditions.

Revision History		
		[bugfix] Invalidate active tool when probe configuration change. [bugfix] Cannot force change to active tool. [bugfix] Protocol errors may lock software until timeout (~2 min). Added driver Virtual CMM. Queued all probe commands for DC and Leitz to prevent timeout. Separated measurement routines from measurement dialog. Added option to exercise the machine. Added initial length measurement for step gauges. Added measurement of step gauge for ASME B89.4.1. Numerous internal changes; improve readability and cleanup.
Jan 14, 2022	2.1	[bugfix] B89 Stepgauge may take point beyond end point. [bugfix] Normalized IJK sphere stem not stored properly. [bugfix] DRO position occasionally shows previous positions.
Jan 30, 2022	3.0	[bugfix] Offsets of current tool configuration not always shown. Added single point measurement. Added monitoring of MeasureView data path for file changes. Minor changes to MeasureView report format.
Mar 2, 2022	3.1	[bugfix] Single point repeat data shows combined repeatability.
Apr 19, 2022	3.2	[bugfix] Cannot delete data if the deleted file already exists.
Jun 12, 2022	3.3	[bugfix] Removed time limit when sending CMM home. [bugfix] Disconnecting I++ client may trigger errors on server.
July 8, 2022	3.4	[bugfix] Circle icon missing when measuring ring or pin gauge. Added description to file name for point repeatability test.
Jan 16, 2023	4.0	Added laser data collection option. Added option for higher resolution DRO for laser. Changed DRO to use fixed with digits. Added option to display laser data in MeasureView.
Mar 24, 2023	4.1	[bugfix] Duplicated options for laser data collection mode. [bugfix] Invalidate active probe following laser with tool offsets. [bugfix] Laser measurement axis defaults to Y axis on startup. [bugfix] Position information incorrect for 10360-2 measurements. Added temperature compensation information dialog.
Apr 12, 2023	5.0	Added option to allow validation of the best fit routines used by MeasureDirect. Documentation update.
May 14, 2024	5.1	[bugfix] Validation data file name missing current day. [bugfix] I++ client pause function not working properly. [bugfix] I++ server error when closing session. Added ability to set tool offsets from I++ client. Added option to display execution queues in debug mode. Update of driver routines.
May 28, 2024	5.2	[bugfix] Removed 'Probe_Data_Valid' entry requirement for laser in

Revision History		
		MeasureView.
Sep 9, 2024	6.0	Removed simulation driver (use *VirtualCMM* as a replacement). Removed simulation points generator. Changed measure dialog to Modal from Modeless. Updated measurement data input fields and display. Added option to measure roll using opposing tools. Reporting format for probe calibration data updated. Reporting format for B89.4.1 stepgauge measurements updated. Added option to set the number of points used for probe calibration. Added option to query tool information for I++. Reduced exercise volume by 10 mm from input coordinates. Probe calibration alignment option restricted to full.
Sep 13, 2024	6.1	[bug fix] IJK vector from controller not reliable on some machines. Using theoretical IJK for measured points in DCC.
Sep 18, 2024	6.2	Improved tracking of the active tool. Added clearance moves for roll measurement and tool calibration. Added option to update the displayed tool offsets when the tool is changed. Redesign of point counter display.
Jan 10, 2025	6.3	[bug fix] – Compile error in debug mode. Wrong display field. Added option to disable inactive communication options. Moved temperature logging options to CMM section.
Jan 16, 2025	7.0	[bug fix] Timing issue for Z roll measurement on I++. [bug fix] Sphere ID/OD determination not reliable. [bug fix] Temperature input fields enabled following measurement. [bug fix] Always query probe information following probe change. Moved temperature monitor to CMM section. Added option to disable inactive communication options. Changed temperature log option from checkbox to button. Added more detailed information for machine settings. Added detailed information for the active tool.
Feb 22, 2025	7.1	[bug fix] AbortE() problems dealing with unexecuted commands. [bug fix] XYZ values not displayed when running some tests.
Apr 27, 2025	8.0	[bug fix] Alignment options did not take tool changes into account. Added Ballbar 10360 measurement. Added option for 3D nominal calibration data.
Apr 30, 2025	8.1	[bug fix] Unable to measure ballbar after first position. Documentation Update
Aug 20, 2025	8.2	[bug fix] Tool calibration not updating controller without a tool change. Active tool data not always updated with new tool data.
Aug 30, 2025	8.3	[bug fix] Sphere stem I value stored with the wrong name. [bug fix] CMM not in manual mode following exercise cycle. [bug fix] Driver queue size not restored following exercise cycle.

Revision History		
		[bug fix] Excessive tool queries sent when running routines. [bug fix] Tool display not updating with roll measurement for I++.