Machine Checking Gauge Users Guide

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Introduction

The *Machine Checking Gauge* utility is software that compliments the Renishaw MCG test artifact. The primary purpose of the *Machine Checking Gauge* utility is to interpret and report data collected by the Renishaw MCG artifact but it can also be used to create a part program necessary for the measurement of the gauge.

Interim checks are necessary to ensure that a coordinate measuring machine is running properly and commonly used to verify that changes to the machine, such as a software upgrade or machine repair, have not adversely affected the accuracy of the CMM. Performing a regular check of the coordinate measuring machine allows tracking of changes in the machine over time and should be done regularly to ensure everything is working properly.

Overview

The *Machine Checking Gauge* utility consists of a main window showing a graphical view of measurements or program path, a detailed analysis view, and a report view. Two additional options for the measurement path and tolerance are included on the left side of the main view in dockable widgets.

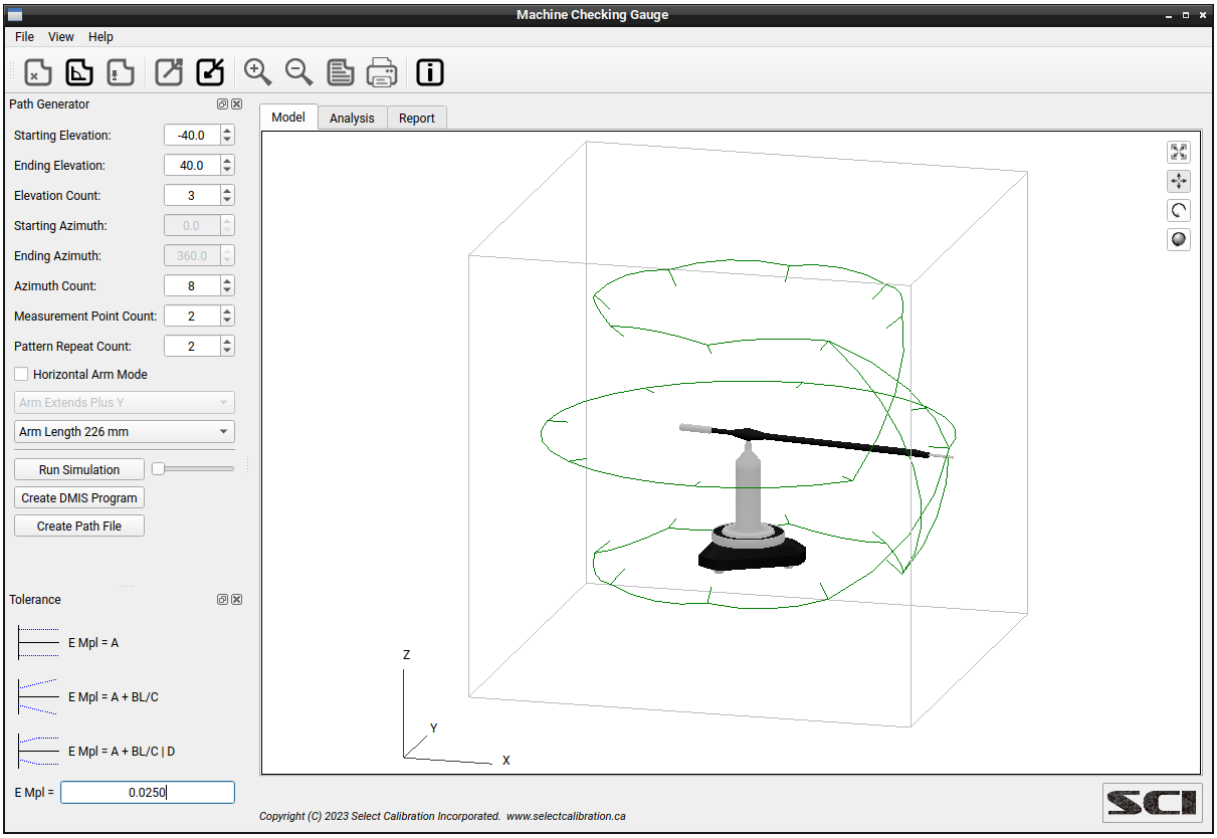


Illustration 1: Main view of the Machine Checking Gauge utility.

Model View

This view shows a 3D representation of the measurement or measurement path. The measurement path is shown when no measurement data is loaded otherwise a representation of the measurement is displayed in the model view. Illustration 2 shows an example of a loaded measurement where each arm position of the measured data is displayed.

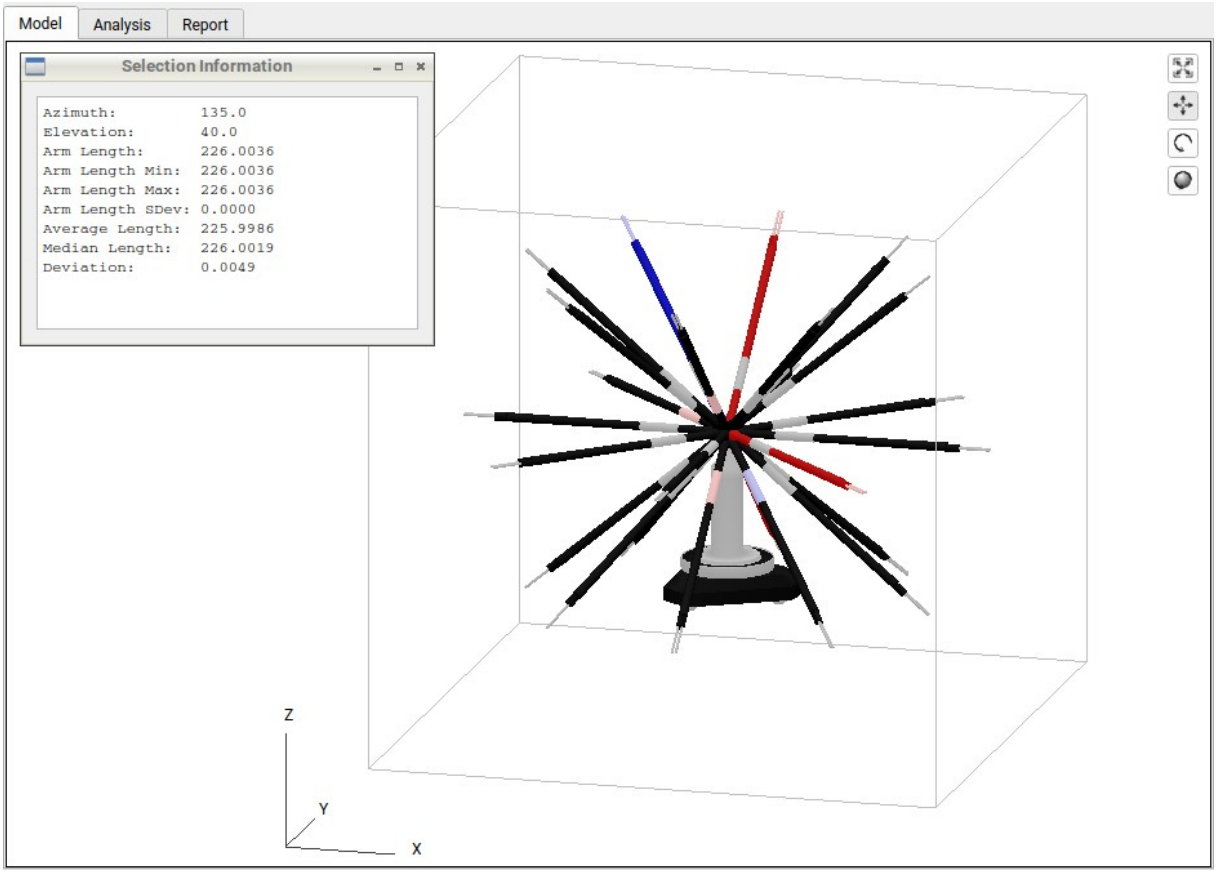


Illustration 2: Display of measurement data showing selection and out of tolerance positions.

Positions that are outside of the tolerance are highlighted in red. Selected positions are highlighted in blue and will show a small information dialog with measurement details.

Graphical View 3D Controls

The 3D model display is not fixed and can be manipulated in a variety of ways as described in the following table:

Image	*Description*
	Scale to fit. Adjusts the scale of the OpenGL Projection matrix to fit the visible data into the display viewport.
	Pan Mode. When enabled a right mouse button click and drag will move the position of the displayed model. For systems with a single mouse button use Ctrl + Mouse.

Image	*Description*
	Rotate 2D Mode. When enabled a right mouse button click and drag will rotate the model around the center of the viewport. For systems with a single mouse button use Ctrl + Mouse.
	Rotate 3D Mode. When enabled a right mouse button click and drag will rotate the model around the click position on the displayed model. For systems with a single mouse button use Ctrl + Mouse.

OpenGL

The graphical view of the measurement data is drawn using OpenGL. The computer must support OpenGL version 2.x or higher in order to run this utility program with a functional 3D view of the measurement data.

Running the *Machine Checking Gauge* utility on computers that only support OpenGL 1.x the model view is replaced with an information window. An example of this information window is shown in illustration 3.

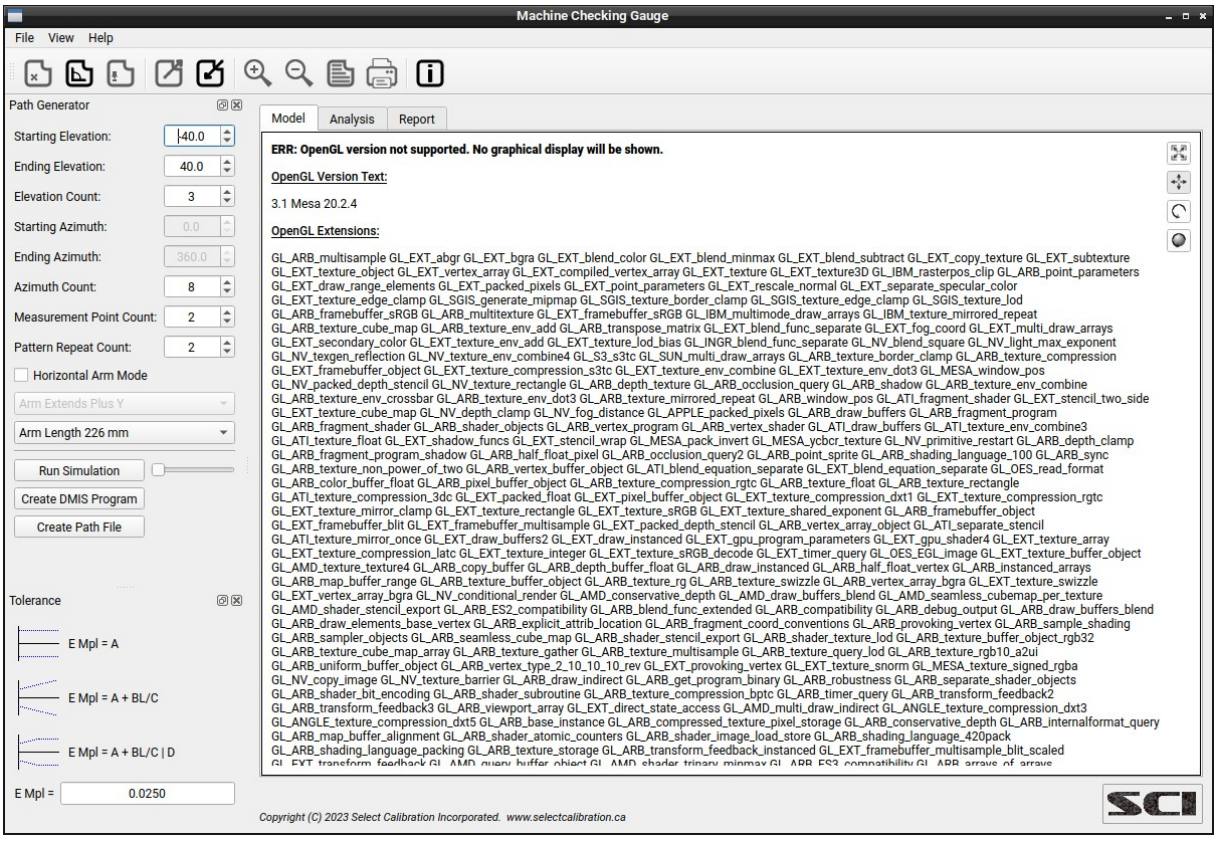


Illustration 3: Model view for unsupported versions of OpenGL.

Analysis View

The analysis view shows numerical details of the measurements and a distribution histogram graph. The analysis information is intended to help identify results which are not typical of the

overall measurements such as fliers or other anomalies. Illustration 4 shows an example of a measurement analysis from a large set of measurement data.

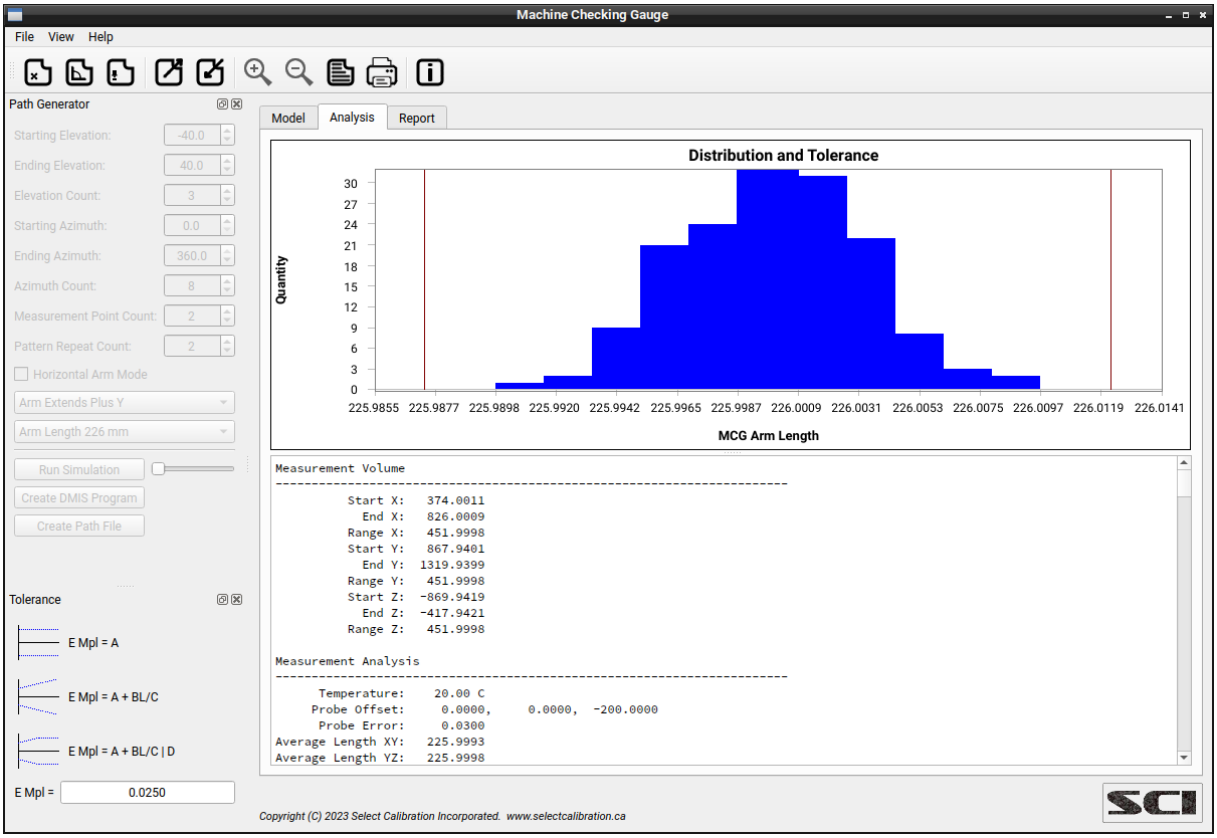


Illustration 4: Analysis view of the current measurement data.

The analysis text includes details of the measurement and may be useful for troubleshooting unexpected results:

```
Measurement Volume
------------------------------------------------------------------------
          Start X:   374.0011
            End X:   826.0009
          Range X:   451.9998
          Start Y:   867.9401
            End Y:  1319.9399
          Range Y:   451.9998
          Start Z:  -869.9419
            End Z:  -417.9421
          Range Z:   451.9998

Measurement Analysis
------------------------------------------------------------------------
      Temperature:    20.00 C
     Probe Offset:     0.0000,     0.0000,  -200.0000
      Probe Error:     0.0300
Average Length XY:   225.9993
Average Length YZ:   225.9998
Average Length ZX:   226.0001
 Average Length X:   225.9992
Relative Length X:    -0.0007
 Average Length Y:   225.9994
```

```
Relative Length Y:    -0.0005
 Average Length Z:   226.0037
Relative Length Z:     0.0038
    Squareness XY:     0.0056 mm/m
    Squareness YZ:    -0.0051 mm/m
    Squareness ZX:    -0.0005 mm/m

Measurement Statistics
------------------------------------------------------------------------
Measurement Count:        155
   Minimum Length:   225.9910
   Maximum Length:   226.0085
   Average Length:   225.9999
    Median Length:   225.9998
    StdDev Length:     0.0033
     Range Length:     0.0176
        Tolerance:     0.0250

Estimated Range for 99% of Measurements: 0.00976
Number Outside of Estimated Range: 19

Measurement Center
------------------------------------------------------------------------
      Pivot Start:   600.0010,  1093.9400,  -643.9420
        Pivot End:   599.9990,  1093.9360,  -643.9340
      Data Center:   600.0010,  1093.9400,  -643.9420

Individual Measurement Results
------------------------------------------------------------------------

Azimuth Elevation  Length      Min         Max     Std Dev   Dev
------------------------------------------------------------------------
   -0.0   -40.0   226.0024   225.9946   226.0060   0.0040   0.0026
   15.0   -40.0   225.9992   225.9867   226.0090   0.0103  -0.0007
   30.0   -40.0   225.9966   225.9845   226.0092   0.0094  -0.0033
   45.0   -40.0   225.9947   225.9872   226.0058   0.0081  -0.0052
  135.0   -40.0   226.0036   225.9949   226.0093   0.0058   0.0038
  150.0   -40.0   226.0024   225.9899   226.0140   0.0108   0.0025
  165.0   -40.0   226.0034   225.9946   226.0107   0.0063   0.0035
  180.0   -40.0   225.9989   225.9855   226.0104   0.0096  -0.0010
  195.0   -40.0   225.9968   225.9890   226.0071   0.0078  -0.0031
  210.0   -40.0   226.0034   225.9888   226.0125   0.0087   0.0035
...
  240.0    40.0   225.9964   225.9877   226.0148   0.0095  -0.0035
  255.0    40.0   226.0033   225.9940   226.0150   0.0075   0.0034
  270.0    40.0   226.0034   225.9876   226.0083   0.0078   0.0035
  285.0    40.0   226.0010   225.9869   226.0113   0.0100   0.0011
  300.0    40.0   226.0019   225.9913   226.0131   0.0075   0.0020
  315.0    40.0   226.0002   225.9881   226.0142   0.0106   0.0003
  330.0    40.0   226.0002   225.9953   226.0066   0.0052   0.0003
  345.0    40.0   226.0004   225.9908   226.0090   0.0067   0.0005
```

Parameter	*Description*
Measurement Volume	The area of the machine containing the Machine Checking Gauge measurement.
Temperature	Temperature recorded during the test.
Probe Offset	XYZ offset of the probe used during the test.
Probe Error	Form error of the measured MCG pivot sphere.
Average Length XY,YZ,ZX	The average of all measurements in these three planes.

Parameter	*Description*
Average Length X,Y,Z	The average length of all measurements along the X, Y, and Z axis.
Relative Length X,Y,Z	The error of the measurements along the X, Y, and Z axis relative to the average length of all measurements.
Squareness XY,YZ,ZX	Measurement of the squareness error of the three projection planes of the machines volume.
Measurement Count	Total number of MCG arm measurements.
Minimum Length	The length of the shortest MCG arm measurement. This is the average of any position and not the absolute shortest length.
Maximum Length	The length of the longest MCG arm measurement. This is the average of any position and not the absolute longest length.
Range Length	Difference in length between the shortest and longest MCG arm measurements.
Average Length	The average length of all MCG arm measurements.
Median Length	The middle length between the shortest and longest measurement. The median length is used when considering the tolerance.
StdDev Length	The standard deviation of the length measurements.
Tolerance	The current working tolerance. This value is defined by entering a tolerance value or expression. Comparison to tolerance uses the median MCG arm length.
Estimated Range for 99%	The range of three standard deviations of the data.
Number Outside Estimated	The total number of length measurements that fall outside the estimated range of the length data.
Pivot Start	XYZ position of the measured pivot sphere before the MCG arm is mounted on the gauge.
Pivot End	XYZ position of the measured pivot sphere after the MCG arm has been removed from the gauge.
Data Center	XYZ position of the best fit sphere from of all the measurement point data. Ideally this position is identical to that of the pivot sphere. *All reported data is calculated from the center of a best fit sphere and does not rely on the mechanical center of the MCG gauge.*
Individual Measurements	A list of all the individual measurements that were used for the calculations.

The starting and ending pivot positions are important when reviewing the data. Most often, if there is a change in the pivot sphere position, the change happened when the MCG arm is either installed or removed but it could also happen during the course of measurement. If the measured results look reasonable even though there is a relatively large shift in the pivot sphere position the shift likely happened when the arm was installed or removed but, either way, the test should be repeated to be certain.

Report View

The report view of the *Machine Checking Gauge* utility shows a preview of how the data will appear when output as PDF file or sent to a printer. An example of the report view is shown in illustration 5.

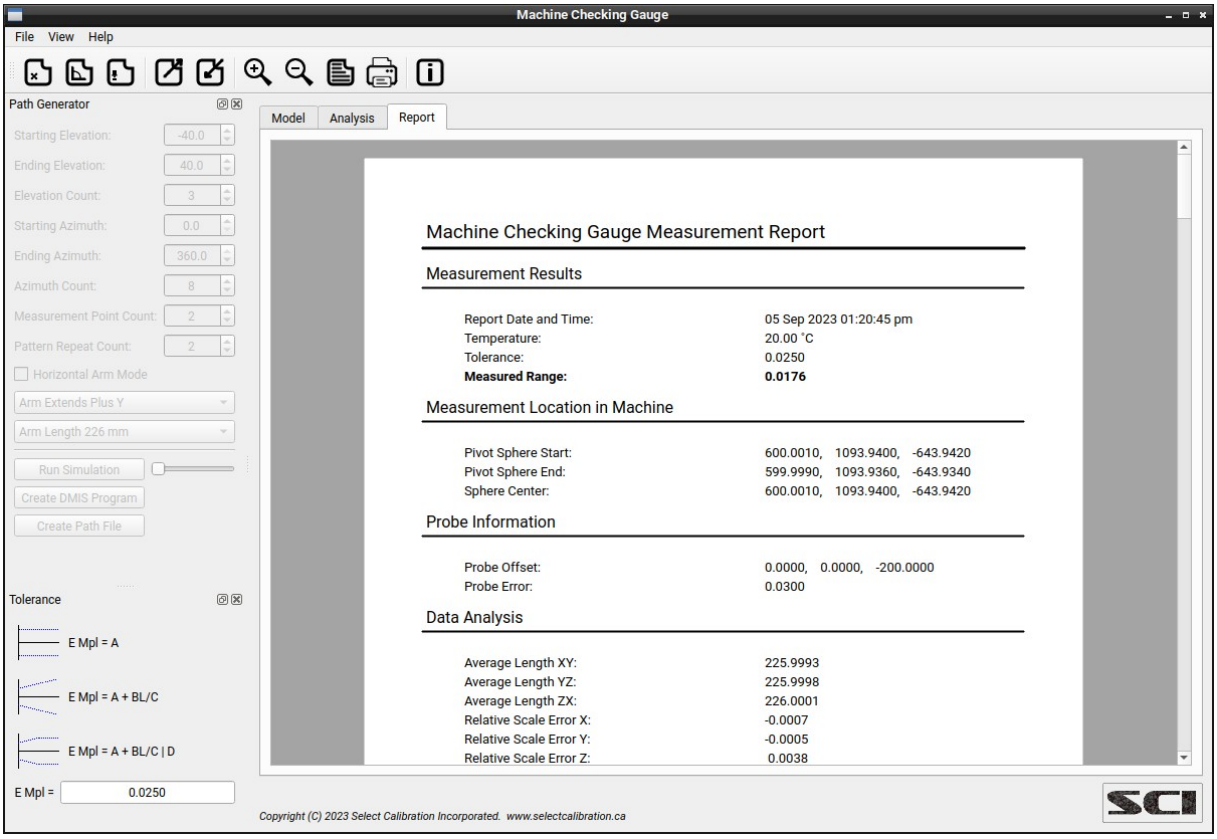


Illustration 5: Report view of the measurement.

The reported date and time is generated when the raw measurement data is processed by the Machine Checking Gauge utility.

Path Generator

This option allows the user to create a measurement path file or DMIS part program that can be used to simplify the measurement of the MCG artifact. Use of the path file can be used to create a simple part program that imports and executes the commands contained within the file. The DMIS program is generic enough that it should be usable on almost any system that supports DMIS programs. If the inspection software cannot create a DMIS output file then it will be necessary to modify the program in order to add a supported output. Most inspect software that translate the DMIS program into a native format and will not generate a DMIS output file but it is assumed any inspection software that uses DMIS as the native language will have the ability to create a DMIS output file.

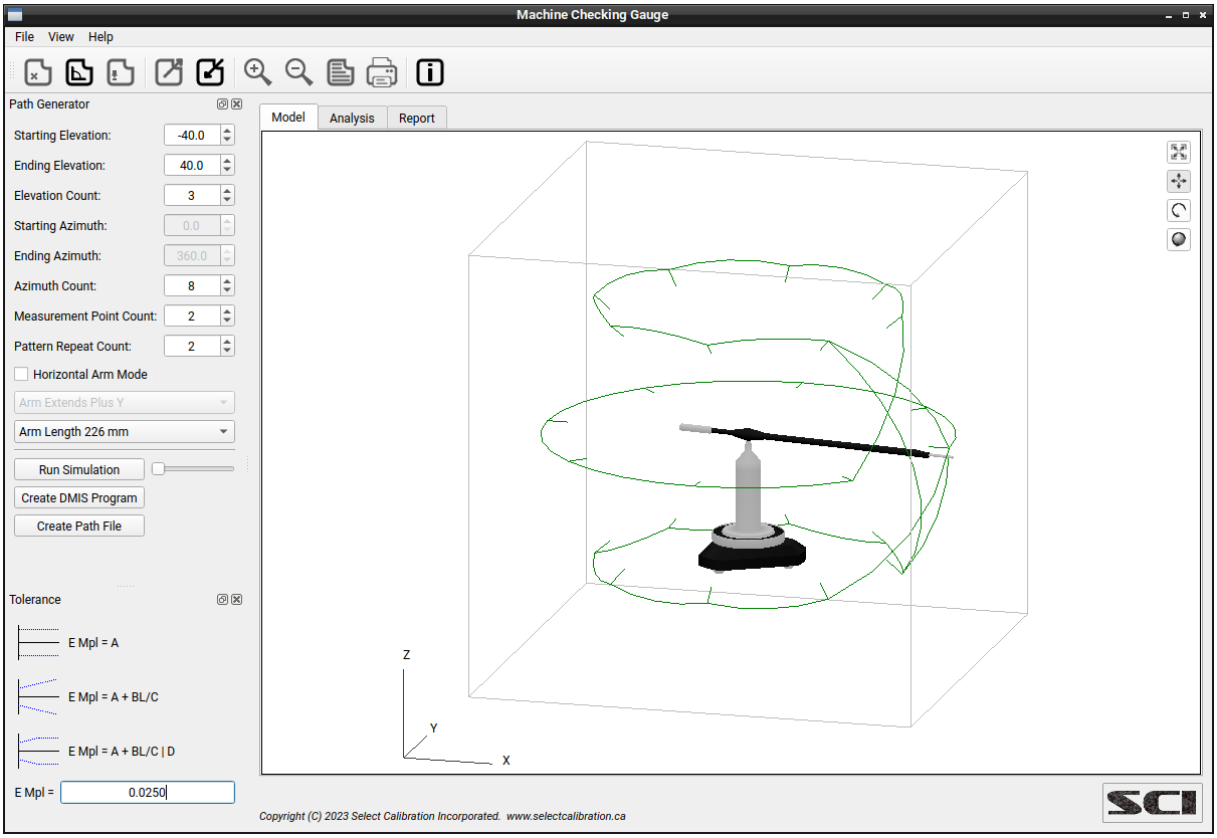


Illustration 6: Path Generator options and end result in the model view.

Options:

Parameter	*Description*
Starting Elevation	Angle in degrees for the starting level of the measurement path.
Ending Elevation	Angle in degrees for the ending level of the measurement path.
Elevation Count	Number of measurement levels between the elevation start and end angles.
Starting Azimuth	Angle in degrees for the starting rotation of the measurement path.
Ending Azimuth	Angle in degrees for the ending rotation of the measurement path.
Azimuth Count	Number of measurement positions between the starting and ending azimuth angles.
Measurement Point Count	Number of times to measure individual points.
Pattern Repeat Count	Number of times to measure the entire pattern of points.
Horizontal Arm Mode	When enabled a circular area of the path is avoided allowing the gauge to be run on horizontal arm CMM's. This area can be defined as +/- X or +/- Y depending on the axis configuration of the machine with the most common being +Y. See Arm Axis section for details.

Parameter	*Description*
Run Simulation	Run a simulation of the measurement pattern in the machine. The simulation will continue endlessly until stopped.
Create DMIS Program	Create a DMIS part program for the inspection of the MCG artifact.
Create Path File	Create the measurement path file.

Arm Axis

When using a horizontal arm there is a section of the gauge that cannot be measured since the arm will collide with the pivot sphere of the MCG artifact. When generating a path in *Horizontal Arm Mode* all moves that are in the shadow of the arm will be avoided.

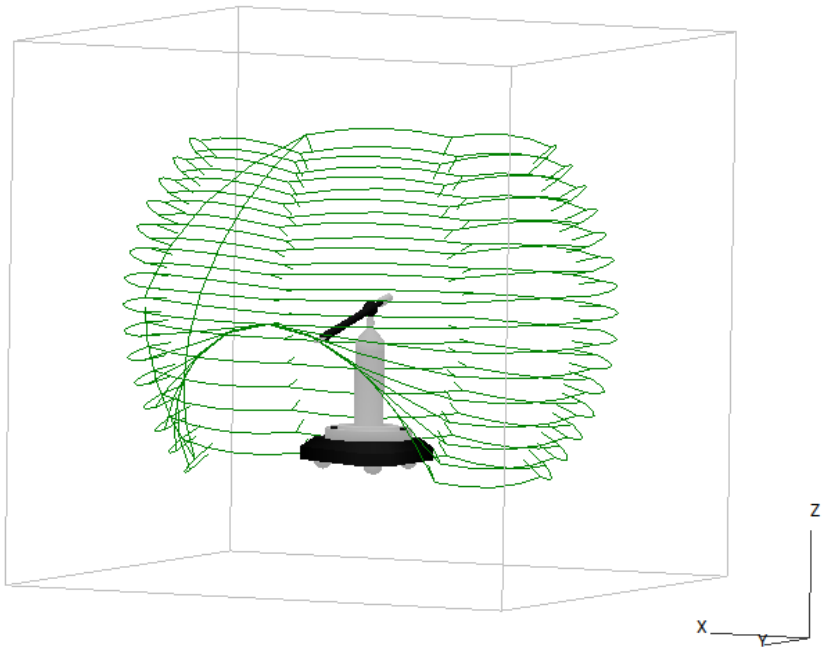


Illustration 7: Example of a section of the measurement sphere avoided on a horizontal arm CMM.

The example shown in illustration 7 was created using many measurement levels in order to clearly show the area that is avoided with the horizontal arm option enabled.

Path File Format

The path file format generated by the Machine Checking Gauge program is intended to be easy to read by any inspection software. An example of a path file is shown below.

```
MCG_PATH_FILE_V1
P 1.000000000 0.000000000 0.000000000
P 0.984807753 0.000000000 -0.173648178
P 0.939692621 0.000000000 -0.342020143
P 0.866025404 0.000000000 -0.500000000
P 0.766044443 0.000000000 -0.642787610
M 0.766044443 0.000000000 -0.642787610
M 0.766044443 0.000000000 -0.642787610
P 0.766044443 0.000000000 -0.642787610
```

```
P 0.733072090 0.143223580 -0.664900231
P 0.683906806 0.283283474 -0.672325780
P 0.619634610 0.417085881 -0.664900231
P 0.541675220 0.541675220 -0.642787610
M 0.541675220 0.541675220 -0.642787610
M 0.541675220 0.541675220 -0.642787610
P 0.541675220 0.541675220 -0.642787610
P 0.417085881 0.619634610 -0.664900231
…
```

The path file has three different types of entries; one is used for validation and the other two are used to define the move and measure points for the measurement sequence.

Line	*Sample*	*Description*
1	MCG_PATH_FILE_V1	Error checking line. If this file is read and this is not the first line then the wrong file has been selected.
2 or higher	P 1.00 0.00 0.00	Move point following by the IJK vector
2 or higher	M 1.00 0.00 0.00	Measurement point followed by the IJK vector

It was decided to have only an IJK direction for all move and measurement points in order to separate the actual length of the MCG arm from the path file. The result is that a single path file can be used to measure any length of MCG arm.

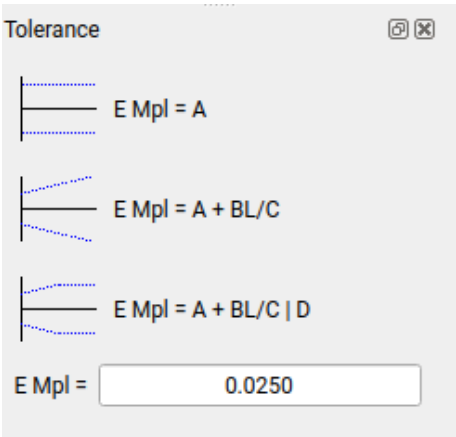
The following is an example of a loop used to read this path file in PC-DMIS. The alignment at this point in the program has the XYZ origin set to the center of the MCG pivot sphere:

```
             ASSIGN/POINT_TYPE=0
             ASSIGN/POINT_I=0
             ASSIGN/POINT_J=0
             ASSIGN/POINT_K=0

             DO/
READ_LINE_RESULT=FILE/READLINE,INPUT_FILE_PNTR,{POINT_TYPE}+" "+{POINT_I}+" "+{POINT_J}+" "+{POINT_K}

             IF/READ_LINE_RESULT == "OK"
             ASSIGN/PNT_VECTOR=MPOINT(POINT_I,POINT_J,POINT_K)

             IF/POINT_TYPE == "M"
             ASSIGN/MEAS_PNT=PNT_VECTOR * MCG_LENGTH
PT1         =FEAT/POINT,CARTESIAN
             [measure point at MEAS_PNT.XYZ with surface normal of PNT_VECTOR.IJK]
             ENDMEAS/
             END_IF/

             ELSE_IF/POINT_TYPE == "P"
             ASSIGN/MOVE_PNT=PNT_VECTOR * (MCG_LENGTH + CLEARANCE)
             MOVE/POINT,NORMAL,<MOVE_PNT.X,MOVE_PNT.Y,MOVE_PNT.Z>
             END_ELSEIF/

             END_IF/

             UNTIL/READ_LINE_RESULT == "EOF"
             FILE/CLOSE,INPUT_FILE_PNTR,KEEP
```

This program should be easy to recreate in almost any inspection software which is the main reason this method exists.

Tolerance

The tolerance option of the *Machine Checking Gauge* utility allows the user to define the upper limit for the range of the measurement lengths. The result from a MCG measurement is comparable to the length repeatability tolerance as defined in the ASME B89.4.1:1997 ball bar test.



The tolerance in the field *E Mpl* and can be in one of the three formats:

- A single value such as 0.010
- An expression based on the length such as 0.010 + 0.005L/1000
- An expression based on the length with a hard limit such as 0.010 + 0.005L/1000 | 0.015

Entries that do not make sense will change the background color of the input field to red.

The tolerance value used for the analysis of the measurement data is treated as a bandwidth from the input tolerance expression. For example, if the input expression is 0.010 mm then the range of the input measurement lengths is expected to be 0.010 mm or less (or +/- 0.005 mm from the median length).

Importing Measurement Data

Data can be imported into the *Machine Checking Gauge* utility by using the import toolbar icon, the import option from the file menu, or by dragging and dropping a measurement file onto the utility.

The imported measurement data has no specific requirements other than to contain a minimum of four unique measurement positions that can be used to calculate a sphere. The order of the imported data is not important. There is no practical upper limit for the number of measurement positions that can be imported.

Data that includes repeated measurement positions are automatically grouped together and reported as a single measurement along with a range and standard deviation. The grouping is done at one degree increments therefore the maximum number of measurement positions that can be theoretically reported is 32,400 (360 x 90).

The analysis of the data is done using all samples that fit within a given measurement range. For example, when calculating the average length along a given axis then all data that is within a

reasonable angle to that axis is used. If there are no suitable positions in the data the report will indicate that that particular value cannot be calculated.

XML File Format

The measurement data collected from the inspection software written to an XML file is expected to appear as shown below.

```
<!DOCTYPE MCG_Measurement>
<MCG_Measurement_Data File_Version="1" Units="MM">
    <Environment>
        <Temperature>21</Temperature>
    </Environment>
    <Probe>
        <Probe_Offset_XYZ>-0.000,-0.000,-195.070</Probe_Offset_XYZ>
        <Probe_Error>0.0000</Probe_Error>
    </Probe>
    <Pivot_Sphere_Initial>
        <Location_XYZ>500.000,750.000,-600.000</Location_XYZ>
    </Pivot_Sphere_Initial>
    <Gauge_Points>
        <Point_XYZ>524.74044,0.00000,-440.30951</Point_XYZ>
        <Point_XYZ>524.74044,0.00000,-440.30951</Point_XYZ>
        <Point_XYZ>371.04753,371.04753,-440.30951</Point_XYZ>
…
        <Point_XYZ>371.04753,-371.04753,440.30951</Point_XYZ>
        <Point_XYZ>371.04753,-371.04753,440.30951</Point_XYZ>
    </Gauge_Points>
    <Pivot_Sphere_Final>
        <Location_XYZ>500.000,750.000,-600.000</Location_XYZ>
    </Pivot_Sphere_Final>
</MCG_Measurement_Data>
```

Line	*Sample*	*Description*
1	<?xml version="1.0" encoding="utf-8"?> *or* <!DOCTYPE MCG_Measurement>	The first line of the file must identify the contents as XML. Either entry will work.
2	<MCG_Measurement_Data File_Version="1" Units="MM">	Identification of the file contents as *MCG_Measurement_Data.* The file version must be indicated (currently 1) and the units must be specified (MM or IN).
<any>	<Environment> <Temperature>20.0</Temperature> </Environment>	Input temperature measurement. Temperature is always assumed to be Celsius.
<any>	<Probe> <Probe_Offset_XYZ>0.0,0.0,-195.0</Probe_Offset_XYZ> <Probe_Error>0.0000</Probe_Error> </Probe>	Probe information. This includes the probe offset and probe error.
<any>	<Pivot_Sphere_Initial> <Location_XYZ>500.0,750.0,-600.0</Location_XYZ>	Location of the MCG pivot sphere at the start of the

Line	*Sample*	*Description*
	</Pivot_Sphere_Initial>	measurement test.
<any>	<Gauge_Points> <Point_XYZ>524.7,0.0,-440.3</Point_XYZ> <Point_XYZ>524.7,0.0,-440.3</Point_XYZ> <Point_XYZ>371.0,371.0,-440.3</Point_XYZ> ... </Gauge_Points>	All points measured on the MCG gauge. The order of the points is not important. The number of measurement points is not limited.
<any>	<Pivot_Sphere_Final> <Location_XYZ>500.0,750.0,-600.0</Location_XYZ> </Pivot_Sphere_Final>	Location of the MCG pivot sphere at the end of the measurement test.
<last>	</MCG_Measurement_Data>	Last line in the measurement file.

Aside from the requirements of a valid XML file the layout of the file is not important.

All measurement point data should be written with a minimum of five decimal precision (in metric). All other values such as the pivot sphere position or probe offset should show at least three decimal place precision (in metric). Using more decimal places is not a problem.

Simple Text Format

The measurement data collected from the inspection software written to a text file is expected to appear as shown below.

```
temperature:21
probe_offset:0.0 0.0 -200
probe_error:0.003
pivot_sphere_start:100.125 200.246 -300.369
pivot_sphere_end:100.126 200.247 -300.370
151.72240447346 0.00364635054 -0.00407155993
107.27960747346 107.28086935054 -0.00454555993
0.00120147346 151.71238835054 -0.00490155993
-107.27420652654 107.27861435054 -0.00464955993
-151.71466952654 0.00136535054 -0.00496355993
-107.28255352654 -107.28368764946 -0.00486955993
...
-75.85836252654 -75.86013364946 107.27542744007
0.00316247346 -107.28478064946 107.27711144007
75.86362847346 -75.86158464946 107.27746844007
```

The initial description entries are all optional but can be added to provide additional information to the *Machine Checking Gauge* utility. The goal of this format was, at a minimum, to allow a file containing only XYZ coordinates of a set of measured points to be imported in the *Machine Checking Gauge* utility.

Text	*Description*
temperature:21	Input temperature measurement. Temperature is always assumed to be Celsius.
probe_error:0.003	Probe error. The form error from

Text	*Description*
	measuring the pivot sphere with 25 points.
probe_offset:0.0 0.0 -200	Probe offset information.
pivot_sphere_start:100.125 200.246 -300.369	Location of the MCG pivot sphere at the start of the measurement test.
pivot_sphere_end:100.126 200.247 -300.370	Location of the MCG pivot sphere at the end of the measurement test.
151.72240447346 0.00364635054 -0.00407155993 107.27960747346 107.28086935054 -0.00454555993 0.00120147346 151.71238835054 -0.00490155993 ...	XYZ points of MCG measurements

The order of the data within the file is not important. Supplemental information including temperature, probe_error, probe_offset, pivot_sphere_start, and pivot_sphere_end are optional.

DMIS DMO Format

The measurement data collected from the inspection software written a DMIS DMO file is expected to contain DMIS formatted actual results. The feature names when the DMIS program is generated is important and should not be changed.

```
FILNAM/'C:\programs\test.dmo',04.0
DA(MAN_CSY)=DATSET/TRMATX,1.,0.,0.,0.,1.,0.,0.,0.,1.,599.998,1093.941,$
-643.949
DA(DCC_CSY)=DATSET/TRMATX,1.,0.,0.,0.,1.,0.,0.,0.,1.,600.001,1093.94,-643.942
OUTPUT/F(MCG_PNT_1),T(X_TOL),T(Y_TOL),T(Z_TOL)
F(MCG_PNT_1)=FEAT/POINT,CART,173.126,0.,-145.27,0.7660444,0.,-0.6427876
T(X_TOL)=TOL/CORTOL,XAXIS,-0.1,0.1
T(Y_TOL)=TOL/CORTOL,YAXIS,-0.1,0.1
T(Z_TOL)=TOL/CORTOL,ZAXIS,-0.1,0.1
OUTPUT/FA(MCG_PNT_1),TA(X_TOL),TA(Y_TOL),TA(Z_TOL)
...
OUTPUT/FA(MCG_SPH_1),TA(MCG_SPH_1_F)
FA(MCG_SPH_1)=FEAT/SPHERE,OUTER,CART,600.001,1093.94,-643.942,3.997,0.,0.,1.
TA(MCG_SPH_1_F)=TOL/CIRLTY,0.03,INTOL
OUTPUT/F(MCG_SPH_2),T(MCG_SPH_2_F)
F(MCG_SPH_2)=FEAT/SPHERE,OUTER,CART,0.,0.,0.,4.,0.,0.,1.
T(MCG_SPH_2_F)=TOL/CIRLTY,0.1
OUTPUT/FA(MCG_SPH_2),TA(MCG_SPH_2_F)
FA(MCG_SPH_2)=FEAT/SPHERE,OUTER,CART,599.999,1093.936,-643.934,4.,0.,0.,1.
TA(MCG_SPH_2_F)=TOL/CIRLTY,0.021,INTOL
ENDFIL
```

In cases where the inspection software does not create a DMIS output file it will be necessary to modify the generated DMIS program to output data in a suitable format that can be imported into the *Machine Checking Gauge* utility.

Exporting Measurement Data

The measurement data can be exported from the file menu or from the export measurement toolbar option of the *Machine Checking Gauge* utility. The format of the exported data is similar to how it appears in the *Analysis* tab of the Machine Checking Gauge utility.

Revision History

Date	*Version*	*Changes*
Apr 18, 2017	1.0	New Program
Oct 25, 2018	2.0	Added simple text format for input data.
Oct 28, 2018	3.0	Added Data section for file management. Added ability to load and save processed MCG data. Improved readability of generated report file Added option to export measurement data. Improvements to appearance of path file. Ability to change the intensity level of the generated path data. Added ability to specify the arm axis of a horizontal arm CMM.
Sep 7, 2023	4.0	Extensive rewrite of user interface. Added option to simulate the measurement positions. Added option to create a DMIS inspection program.