Bringing Touch Trigger Probe CMM Calibration In House

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Purpose

This paper will present the in-house development and implementation of a calibration process for calibrating touch trigger probe CMM's using a Master Ball and Step Gages.

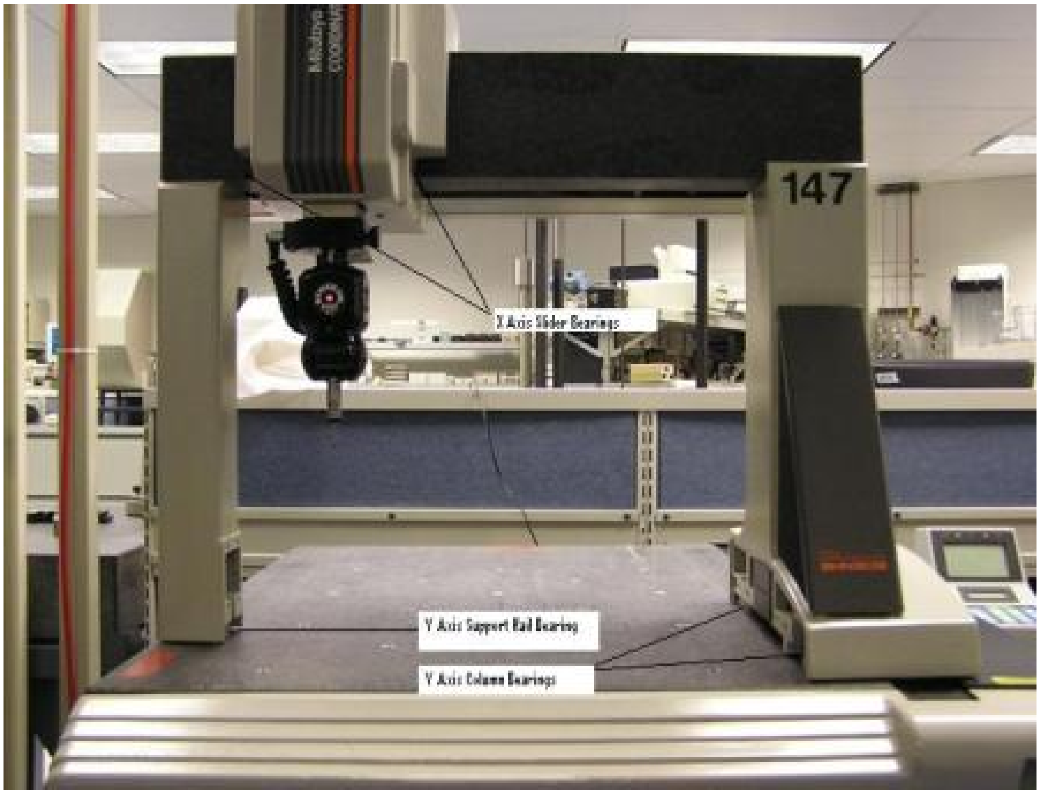
Topics covered

- ♣ Issues and Problems Encountered During the Development
- ♣ Uncertainty Components and a Uncertainty Budget
- ♣ Calibration Process
- ♣ Future Improvements
- ♣ Conclusion

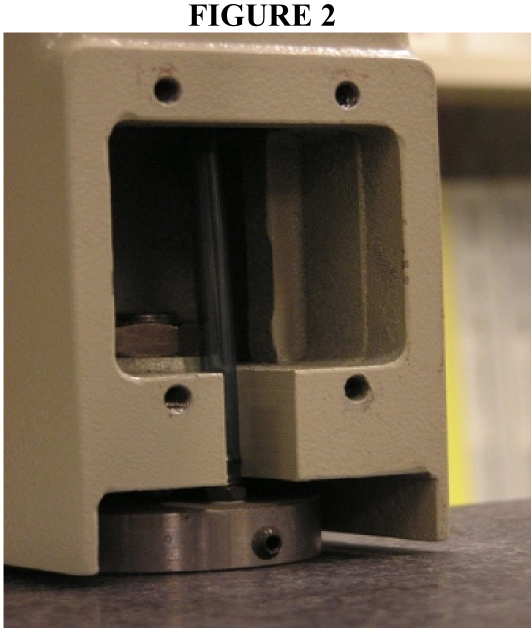
CMM Background

The CMM is a measuring system capable of measuring spatial coordinates and with the means to move a probing system when determining coordinates of points on a work piece surface. There are eleven types or styles of CMM's, we will be talking about a Moving Bridge style CMM in this paper. The Bridge Type Carriage, which slides in the Y-axis direction, consists of a column, the support and X axis beam. The Y axis guide uses a narrow guide method, and the Y axis rail is held between two pairs of precision air bearings that are built into the column. The entire carriage is floated by three air bearings; two on the column side and one on the support side. The X axis slider is supported by the precision air bearings and it moves in the X axis direction (right and left) along the beam which serves as the guide for the axial movement. The Z axis spindle moves in the Z axis direction (up and down) guided by two sets of precision air bearings located in the front part (upper and lower) of the Z axis slider. Each set of air pads holds the Z axis spindle from four sides; right and left, front, and rear. There is also a Z axis air cylinder inside the Z axis spindle. The Z axis spindle is balanced by compressed air in the cylinder which compensates for the mass of the Z axis spindle and probe.
Traditional CMM's have perpendicular moving elements (axis). These elements create a real physical three dimensional reference frame. Each axis has six degrees of freedom. There are three additional perpendicularity conditions (X-Y, Z-X, Y-Z) the CMM model has 21 (3x6+3) error parameters (error sources). They are yaw, pitch, roll, vertical and horizontal straightness, and linear positioning.

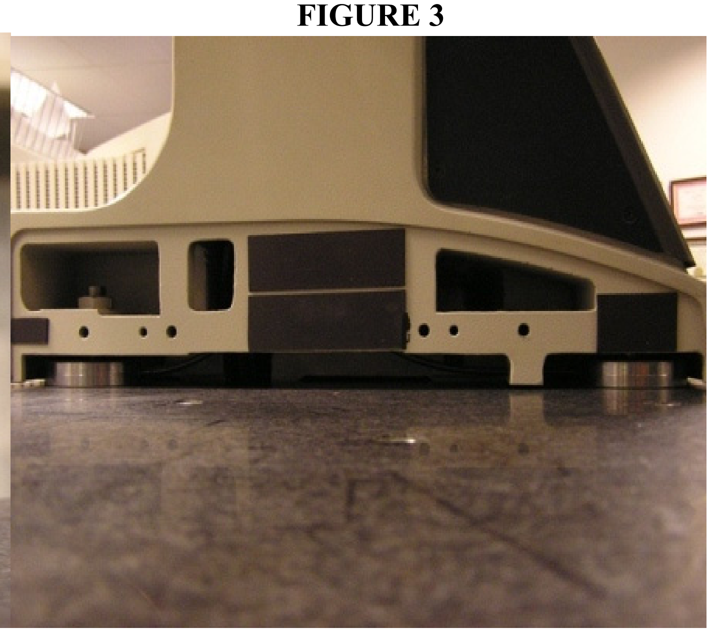
(MOVING BRIDGE CMM)
FIGURE 1



(LEFT SUPPORT RAIL BEARING)
FIGURE 2



(RIGHT COLUMN BEARINGS)
FIGURE 3



The Motorized Coordinate Measuring Machine or (CMM) typically consist of the following components:

- Granite Base
- Light Moving Bridge
- Ceramic, Aluminum Ram
- Air Bearings
- Glass Scales
- Ball Screw, Belt, Band, Friction Drive
- Touch Trigger Probe

In-House Development

As part of an in house development for calibrating CMM's training is needed to be familiar with the operation of a touch trigger probe CMM. The following CMM training was researched and is available from the following sources: (IDW) Workshop, Dimensional Workshop at the (NRC), CMM Basics and Coordinate Measuring Machine CMM Workshop at the (NRC), (WPT) CMM operation and calibration, (Ridgewater College) CMM basics, and on site training from the manufacture.

Most manufactures will offer a one day CMM Introduction training class and a hands on CMM calibration, maintenance and adjustment training. Also, as part of this training process a local representative from David Olson Sales (Peter Martignacco) who is very knowledgeable about CMM's can give a software operating system and software program training. The following is a training list of topics available.

One day CMM introduction:

a. Classroom course, fundamentals of Testing CMM's
b. Covers all the important testing methods
c. Includes both National and International standards
d. Discusses important CMM error sources
e. Review Measurement Uncertainty for Calibrating CMM's
f. Presentation of Mitutoyo America's A2LA Accredited procedures
g. Includes handout material

One day Hands On Calibration, Maintenance and Adjustment of CMM's

a. Hands on your CMM's
b. Covers important maintenance and calibration issues
c. Includes training in adjusting the CMM to bring it back to specification
d. Provide direction in developing your CMM calibration program

One day Operating System Training:

a. Right Hand Rule
b. Key board Functions
c. Coordinate System (Fixture and Machine)
d. Joy Stick
e. Probe System
f. Measuring
g. Repeat, Edit modes
h. Tolerance and Statistics functions

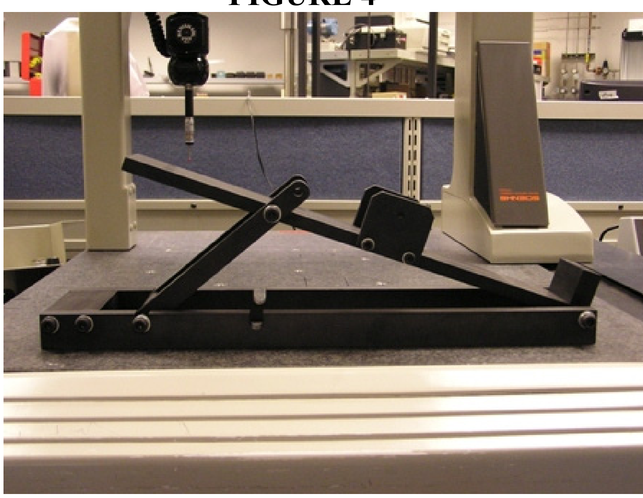
One day software programming training:

a. Program Setup and Learn Mode
b. CNC Movement and Measurement Commands
c. Alignment and Setting Origins
d. Saving and Recalling Coordinate Systems
e. Setting Looping
f. Setting and Generating Datapak Files
g. Creating Volumes and Directories for Programs and Data
h. Editing and Modifying and Copying Programs

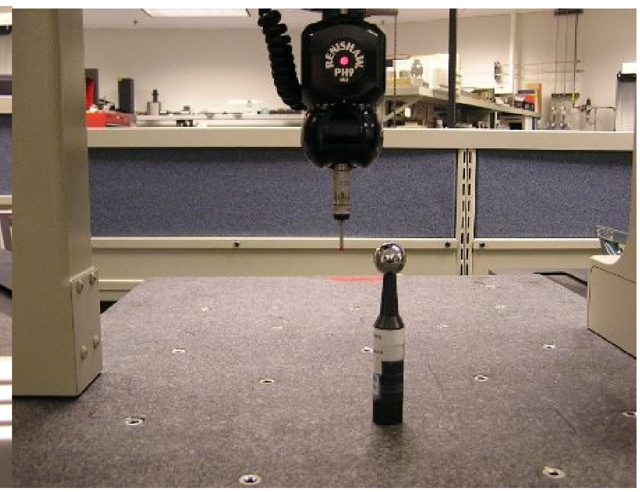
The first step for an in house CMM calibration program is to purchase the correct calibration standards, get accredited calibrations, which include the following:

- Inclination stand (volumetric)
- Masterballs (accredited calibration)
- Square (squareness)
- Indicator (squareness)
- 18 inch step gage
- 24 inch step gage

(INCLINATION STAND)
FIGURE 4

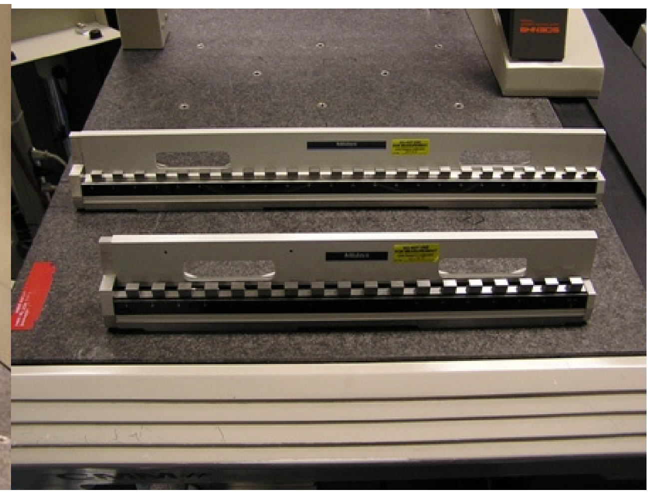


(RENISHAW MASTERBALL)
FIGURE 5



(SQUARE AND INDICATOR)
FIGURE 6

(STEP GAGES)
FIGURE 7



The second thing to do for an in house CMM program is to determine the components for uncertainty and develop an uncertainty budget:

Table 1. Uncertainty for 1 meter length measurement in 20±1°C environment.

Symbol	Uncertainty Source	Type	Limit Value	Units	Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty
Um	Step gage	B	1.50	µm	Normal	2.00	1.00	0.75
Ur	Repeatability	B	0.50	µm	Normal	1.00	1.00	0.50
Uts	Measurement of scale temperature	B	0.20	°C	Normal	2.00	8.00	0.80
Utm	Measurement of master temperature	B	0.15	°C	Normal	2.00	10.00	0.75
Uas	UNDE of scale	B	0.40	µm/m°C	Rectangular	1.73	1.00	0.23
Uam	UNDE of master	B	0.50	µm/m°C	Rectangular	1.73	1.00	0.29
Uc	Combined standard uncertainty (in µm)							1.5
U	Expanded uncertainty using coverage factor k = 2 (in µm)							3.0

Table 2. Uncertainty for 1 meter length measurement in 20±5°C environment.

Symbol	Uncertainty Source	Type	Limit Value	Units	Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty
Um	Step gage	B	1.50	µm	Normal	2.00	1.00	0.75
Ur	Repeatability	B	0.50	µm	Normal	1.00	1.00	0.50
Uts	Measurement of scale temperature	B	0.60	°C	Normal	2.00	8.00	2.40
Utm	Measurement of master temperature	B	0.45	°C	Normal	2.00	10.00	2.25
Uas	UNDE of scale	B	0.40	µm/m°C	Rectangular	1.73	5.00	1.15
Uam	UNDE of master	B	0.50	µm/m°C	Rectangular	1.73	5.00	1.45
Uc	Combined standard uncertainty (in µm)							3.9
U	Expanded uncertainty using coverage factor k = 2 (in µm)							7.8

As part of the uncertainty budget process the third step for an in house CMM program is to develop an equipment calibration specification:

Equipment Specification

- Floor Unit
- Power Source - 110 VAC (Typical)
- Calibrated Stage Area - X-12", Y-18", Z-10" (Typical)
- Probe Head - PH9
- Probe - TP2 or TP20
- Stylus (BHN305 / BRT504)
  - Stylus Length x Ruby Dia - 21mm x .5mm (Typical)
  - Stylus Adaptor Length (M2 to M3) - 7mm (Typical)
- Stylus (BHN506) – Receiving Inspection
  - Stylus Length x Ruby Dia - 10mm x .5mm (Typical)
    - 20mm x 1mm (Typical)
    - 20mm x 4mm (Typical)
  - Stylus Adaptor Length (M2 to M3) - 20mm (Typical)
  - Stylus Adaptor Length (M2 to M3) - 5mm (Typical)
- Range (BHN 305) - X=13", Y=20", Z=12"
- Range (BHN 506) - X=20", Y=24", Z=12"
- Range (BRT 504) - X=19.68", Y=15.74", Z=15

- Axial Length Measuring Accuracy: 2.6+4L/1000 µm or 102+4L micro inches
- Volumetric Length Measuring Accuracy: 3+4L/1000 um or 118+4L micro inches
- X, Y, & Z Axis Repeatability Accuracy: +0.00006/-0.00006 Inch

- Bridge Parallelism Accuracy: ≤ 0.0001 Inch *
- XZ, YZ and XY Squareness Accuracy: ≤ 0.0001 Inch *
- Masterball Repeatability Accuracy: ≤ 0.0001 Inch
- Probe Performance Accuracy: ≤ 0.0002 Inch

* The Bridge Parallelism and Squareness Accuracy's are used as guidelines to help maintain proper alignment of the machine and therefore will not have out of tolerance conditions reported.

The next step for an in house CMM program is to develop set up parameters for a touch trigger probe CMM:

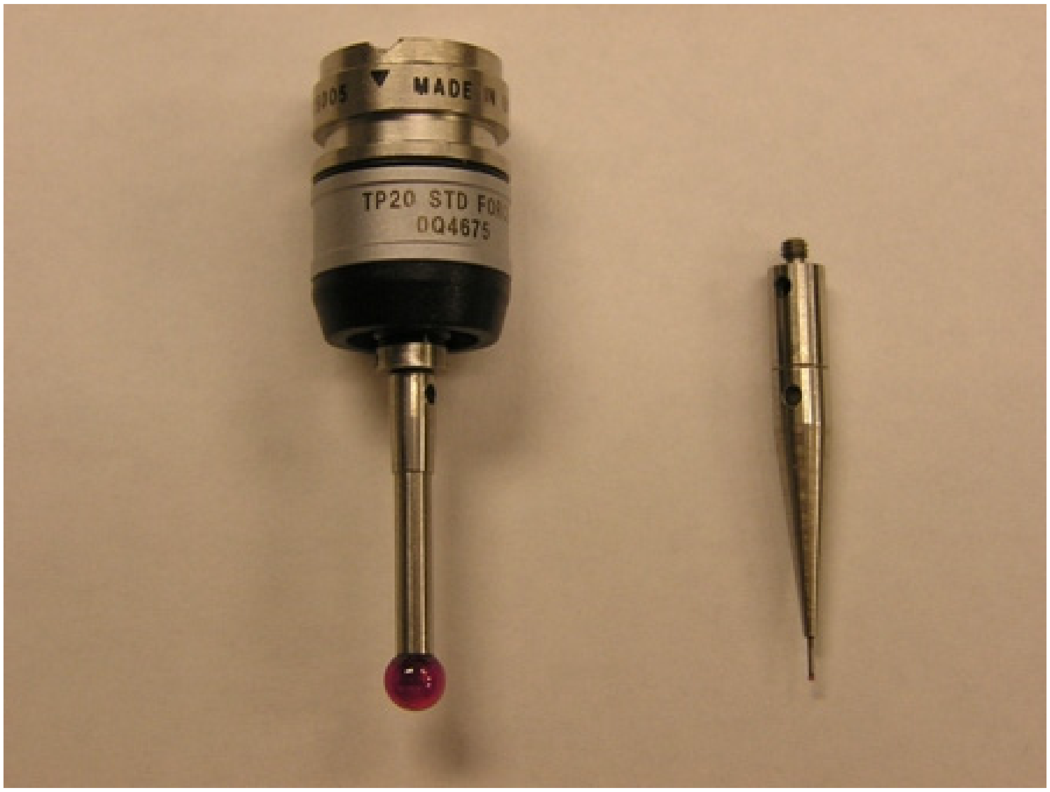
As part of the initial setup, the following parameters had to be established:

- Probe Stylus Tip Size
- Y Axis Alignment
- Volumetric fixture set up
- Positioning of the step gage
- Stylus calibration angles
- Position or location of the probe

Probe Stylus Tip Size

The 5mm probe stylus tip size for calibration was recommended by Manufacture. See below an example of the 5mm stylus and the measurement stylus that might be used in a production environment.

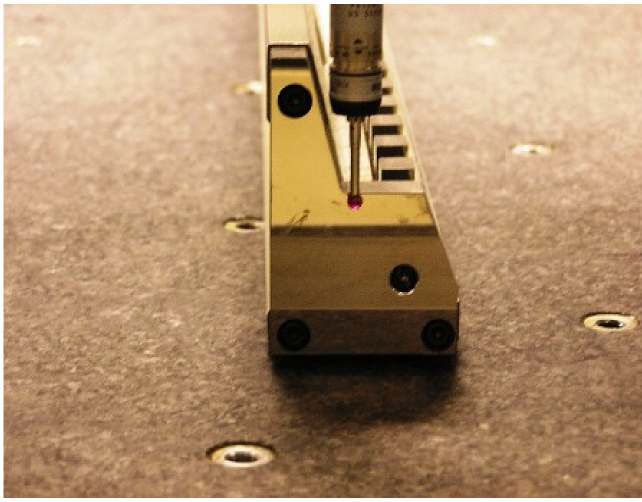
(PROBE STYLUS TIP SIZE)
FIGURE 8



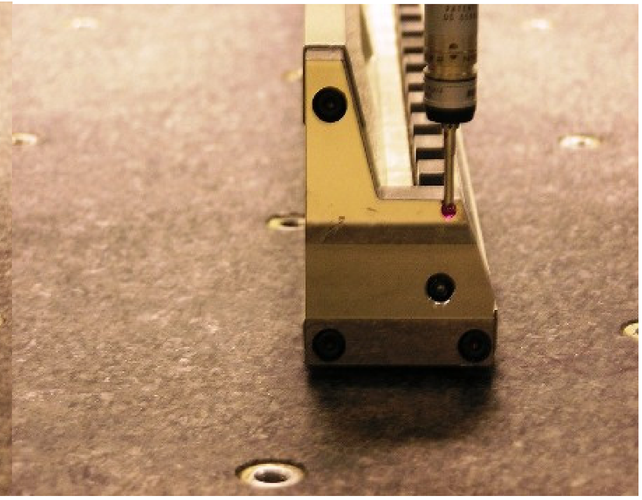
Y Axis Alignment (Alignment of the step gage to the x-axis)

The step gage is positioned on the CMM granite surface plate in the Y Axis and is aligned in the X Axis through the software program. The process included setting it up in Figure 9 and then the CMM will move to the position in Figure 10. The operator then verifies the A2, A3 measurement on the CMM computer screen is within 20 micro inches, if it is not within 20 micro inches the operator taps on the step gage and repeats the program until it is aligned within 20 micro inches. The program is set up for 31 steps in order to get a good alignment. This alignment will help in reducing any errors in the Y Axis measurements.

(Y LIN ALIGNMENT)
FIGURE 9



(Y LIN ALIGNMENT)
FIGURE 10

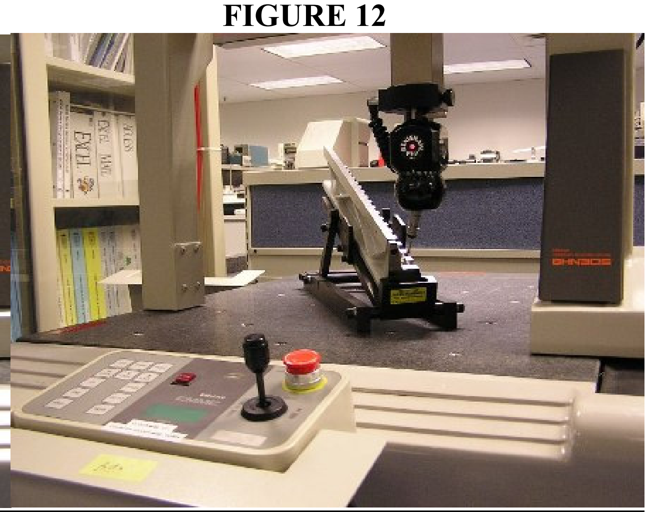


Volumetric Fixture Set Up

The volumetric fixture is an inclination stand that is set up at an angle and set in the four corners of the CMM. The inclination stand is positioned at a height and spot on the CMM granite surface plate that is within the axes displacement range.

(DIAGINAL VOLUMETRIC 1)
FIGURE 11

(DIAGINAL VOLUMETRIC 2)
FIGURE 12



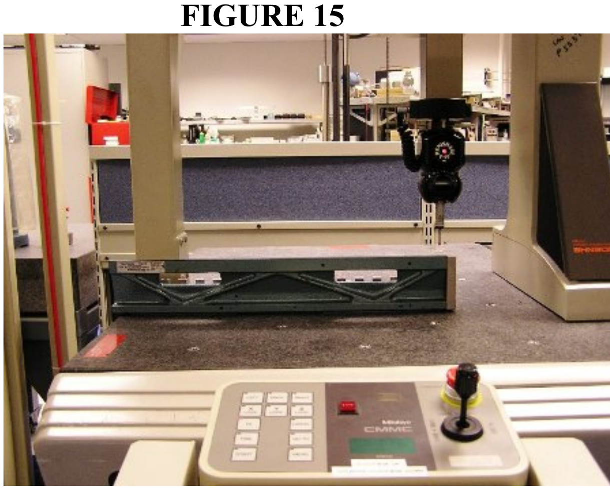
(DIAGINAL VOLUMETRIC 3)
FIGURE 13

(DIAGINAL VOLUMETRIC 4)
FIGURE 14

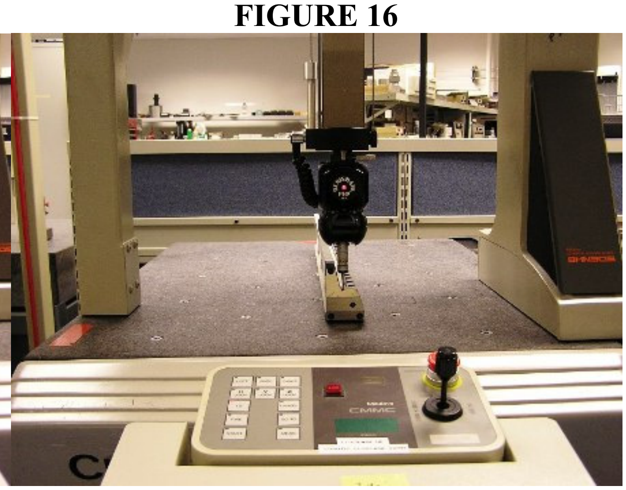
Axial Fixture Setup

The step gage is measured in the Uni-Directional direction for the X, Y, and Volumetric Axial Length Accuracy. The Z Axial length Accuracy is measured in the Bi-Directional direction. See set up Figures 15, 16, 17 for the X, Y, Z axis below.

(X AXIS SET UP)
FIGURE 15



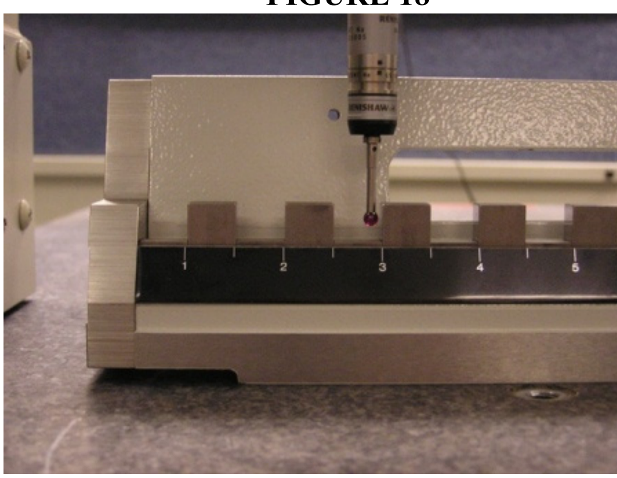
(Y AXIS SET UP)
FIGURE 16



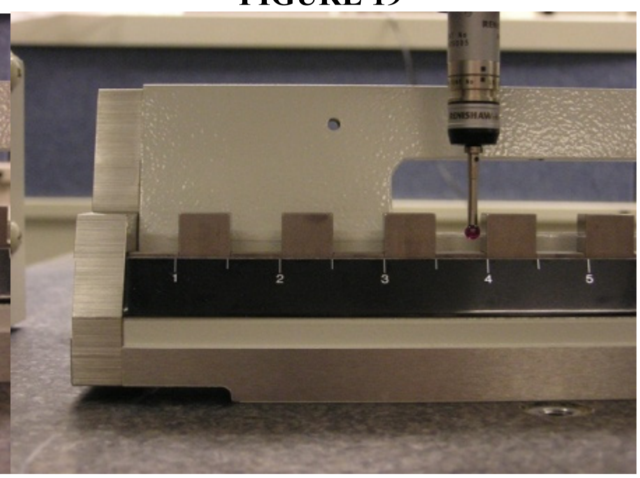
(Z AXIS SET UP)
FIGURE 17

The following is examples of uni-directional and bi-directional direction set ups:

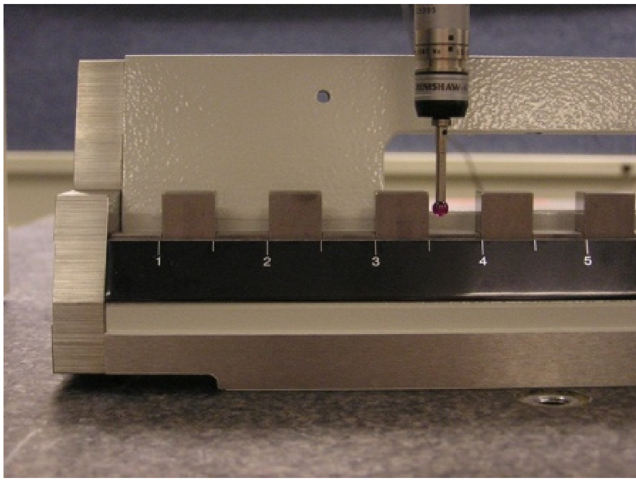
(UNI-DIRECTIONAL SETUP START)
FIGURE 18



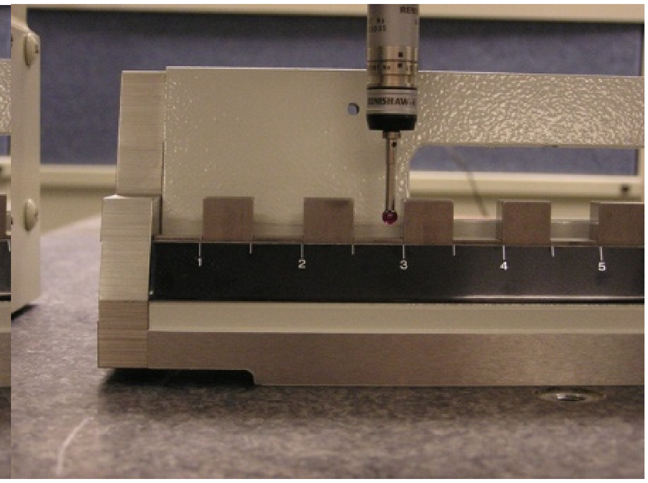
(UNI-DIRECTIONAL SETUP END)
FIGURE 19



(BI-DIRECTIONAL SETUP START)
FIGURE 20



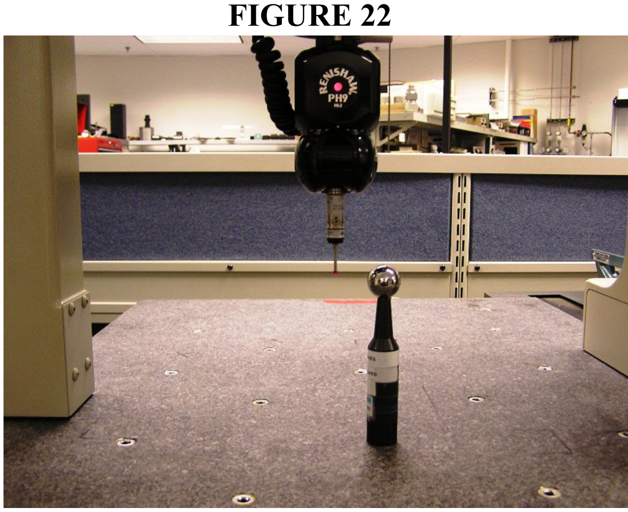
(BI-DIRECTIONAL SETUP END)
FIGURE 21



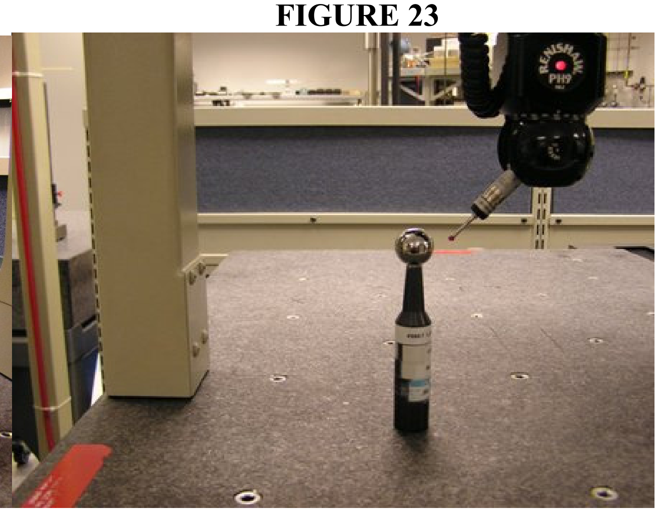
Calibration of Stylus Angles on the Masterball

The stylus used must first be qualified; in other words, their diameters and the X, Y, Z distances of their center points have to be determined. For this purpose, a high precision sphere (Masterball) is probed in no less than five points with the stylus. This data is later taken into account by the software in all subsequent measurements, to the effect that the zero tip diameters and their zero distances are "compensated out" of the results. It is also recommended to recalibrate the stylus when the environment changes.
The 5mm stylus was calibrated on the Masterball at nine different orientations.

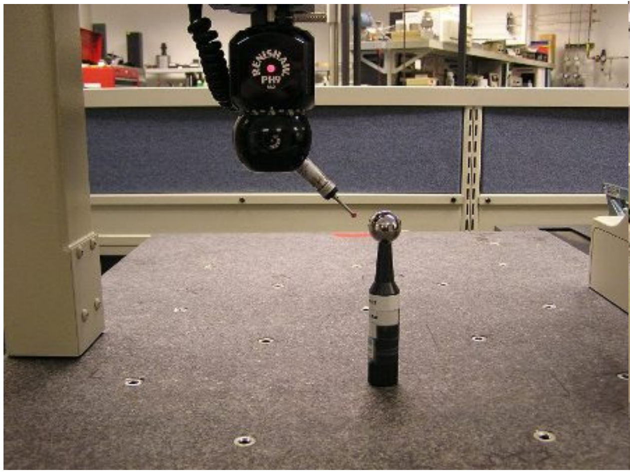
(STYLUS POS #1)
(X = 0.0, Y = 0.0)
FIGURE 22



(STYLUS POS #2)
(X = 45.0, Y = -90.0)
FIGURE 23

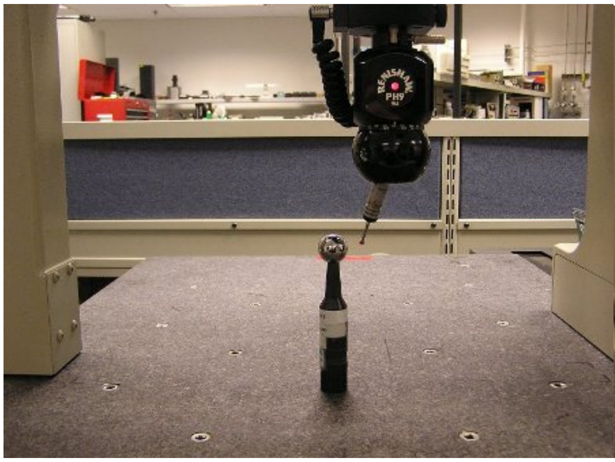


(STYLUS POS #3)
(X = 45.0, Y = 90.0)
FIGURE 24

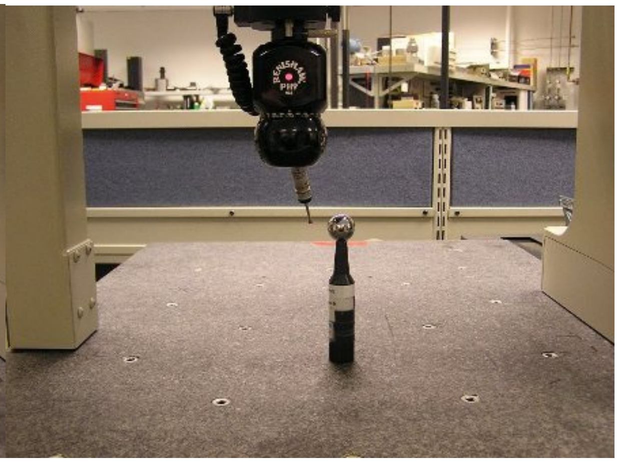


(STYLUS POS #4)
(X = 90.0, Y = 90.0)
FIGURE 25

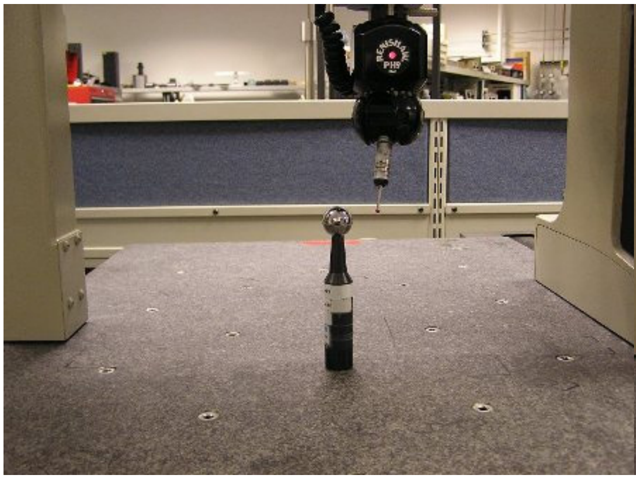
(STYLUS POS #5)
(X = 22.5, Y= -135.0)
FIGURE 26



(STYLUS POS #6)
(X = 22.5, Y = 150.0)
FIGURE 27

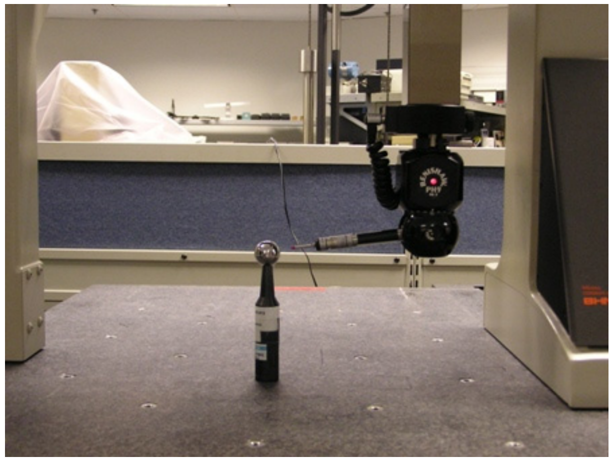


(STYLUS POS #7)
(X = 22.5, Y = -22.5)
FIGURE 28



(STYLUS POS #8)
(X = 22.5, Y = 30.0)
FIGURE 29

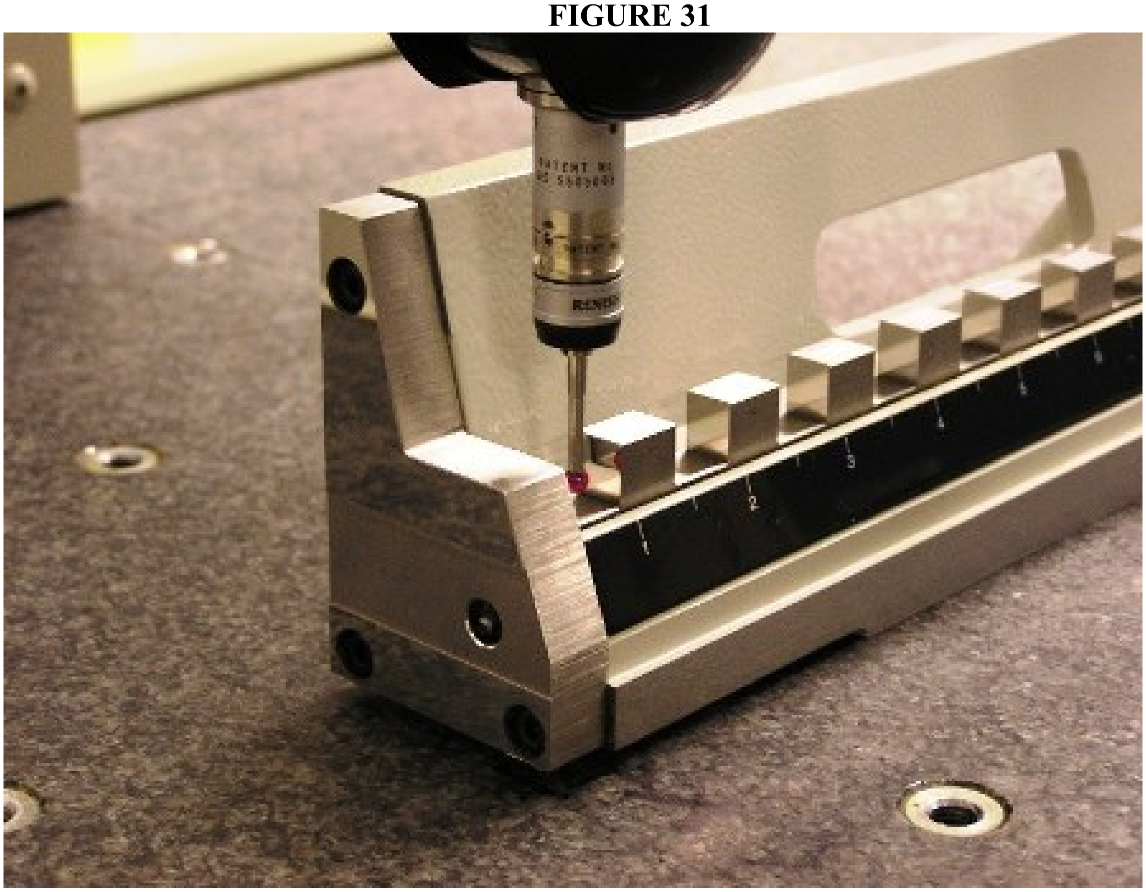
(STYLUS POS #9)
(X = 82.5, Y = 90.0)
FIGURE 30



Position of Probe Tip on Step Gages for Measurement

The position of the stylus when taking measurements is very critical and should be set up to be half the height and half the width of the gage block on the step gage for each inch increment. Also, when the step gage is calibrated by an accredited source the calibration vendor should also record the actual location that is calibrated to reduce any errors.

(PROBE TIP POSITION)
FIGURE 31



The last step for an in house CMM calibration program is to develop a calibration process.

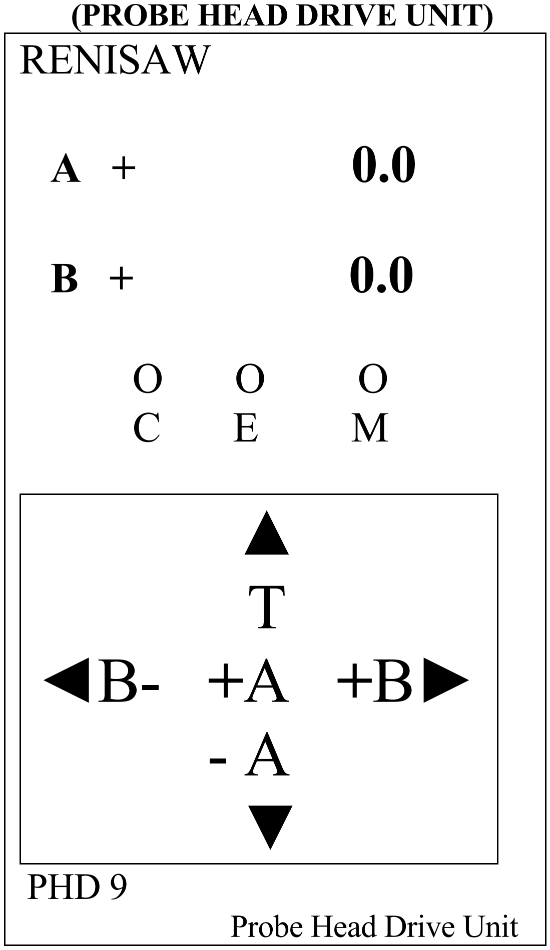
The calibration process may consist of the following tests that are based on ASME B89 and ISO 10360 standards:

- Masterball Calibration
- Masterball Repeatability
- Probe Performance
- X, Y, Z Axis Length Measurement
- Diagonal Length Measurement (Volumetric)

Masterball Calibration

The Masterball calibration may consist of calibrating the Masterball diameter at nine difference orientations or angles using the probe head drive unit.

FIGURE 32
(PROBE HEAD DRIVE UNIT)



Manually calibrate the following stylus positions (1-9) see TABLE I below for probe position.

TABLE I
(PROBE DIRECTION CHART)

Probe #:	Probe Direction	Definition
1	|	X = 0.0 Y = 0.0
2	/	X = 45.0 Y = -90.0
3	\	X = 45.0 Y = 90.0
4	┘	X = 90.0 Y = 90.0
5	\	X = 22.5 Y = -135
6	\	X = 22.5 Y = 150
7	/	X = 22.5 Y = -22.5
8	/	X = 22.5 Y = 30.0
9	└	X = 82.5 Y = -90.0

Verify the Diameters (X, Y, Z) are within ± 0.0002.

The nine different stylus orientations represent the following calibrations that should be performed:

CALIBRATIONS PERFORMED
TABLE II

MASTERBALL REPEATABILITY
PROBE PERFORMANCE
X AXIS LENGTH ACCURACY
Y ALIGNMENT
Y AXIS LENGTH ACCURACY
Z AXIS LENGTH ACCURACY
DIAGONAL/VOLUMETRIC 1
DIAGONAL/VOLUMETRIC 2
DIAGONAL/VOLUMETRIC 3
DIAGONAL/VOLUMETRIC 4

Calibration Process definitions:

Masterball Repeatability

The Masterball Repeatability consists of calibrating the 5mm stylus on the Masterball on top and 4 points around the equator and then the CMM will repeat it 5 times.

Probe Performance

Probe performance consists of calibrating the 5mm stylus on the Masterball on top and three series of eight points around the equator for a total of 25 measurements.

X, Y, Z Axis Length Measurement

The X, Y Axis Length Measurement consists of measuring the step gage in the Uni-direction within the axis range and performing the measurement three times for repeatability. The measurements were done in 1” increments starting at the 1½” gage block.

The Z Axis Length Measurement consists of measuring the step gage in the Bi-direction within the axis range and performing the measurement three times for repeatability. The measurements were done in ½” increments starting at the ½” gage block.

Diagonal Length Measurement

Diagonal Length Measurement consists of measuring the step gage on an inclination stand at an angle in four different corners of the CMM in the Uni-direction and then done three times for repeatability.

Problems that may arise when developing an in house CMM calibration program:

Turnaround time to get the 18” and 24” step gages from overseas and then have them calibrated from an accredited calibration lab may not be in a timely manner.

May need an extension added to the probe to measure in the z axis, and to qualify it.

Axis displacement may exceed the machine range when setting up the standards

- o Added set up dimensions to process for fixture locations

Add Masterball diameter into software for reference look up table for Tolerancing

- o Added actual data from the Certificate

Future Improvements to calibrate CMMs in house

- Design a set up fixture inside the CMM range for the step gage for consistency
- Monitor the temperature of the glass scales
- Improve the mechanical adjustment steps in the calibration process
- Get Software Adjustment capability from the Manufacture
- Participate in Measurement Assurance Program with at least three other labs

Conclusion

Temperature is the most significant uncertainty contributor for the CMM. This can be reduced by performing the calibration in a controlled environment, monitoring the temperature gradients around the CMM and also monitoring the temperature of the glass scale, step gages and masterball. The biggest factor not to use the Laser Interferometer method is because it does not consider the PH9 probe errors, which is what is used to measure or inspect product or material. Also, the Laser may read in the positive direction and the step gage in the negative direction due to the set up in the Laser software. The Laser has an environmental compensation but does not take into consideration of how the machine is operating, which can add an additional bias to the results. This can contribute to about 100 micro-inches of uncertainty to the measurement process. This is not acceptable, as other uncertainty components still need to be taken into account.