

Error Map Rotation Point

Table of Contents

Purpose.....	3
Software Error Correction.....	3
Example With X Axis Roll.....	4
Case 1: Mechanical and Compensation Point Identical.....	4
Case 2: Mechanical and Compensation Point Not Identical.....	5
Simulation of Straightness Errors.....	6
Real World Example.....	7
Known Issues from Non-Mechanical Rotation Points.....	8
Compensation Map Conversion.....	9
Revision History.....	10

Error Map Rotation Point

Purpose

This article describes the significance of the position selected for the compensation error map rotation point for a coordinate measuring machine. In a perfect world the application of the compensation data will behave exactly the same as the mechanical error but there is usually a bit of difference as the compensation methods are often generic. For physical angular errors the measurable straightness error is always zero at the point where the mechanical rotation occurs. The rotation point of the compensation map is a description where rotational corrections are calculated from, and ideally the same, as the mechanical rotation point.

One type of compensation error map that tries to calculate the angular correction from the mechanical rotation points of the machine is Virtual DMIS. This map has a long list of entries for distances from the edges of the volume to the points where the mechanical rotation are likely to exist for every angular parameter. Despite the manufacturer documenting the different offsets all examples observed in the field have the majority of entries set to zero for unknown reasons. This map would behave like any other generic compensation error map if the offsets are not set properly.

The rotation point for the angular compensation data can be set to locations that will simplify data collection for a CMM axis eliminating the need to layer data collection. This method is commonly used by some software but it does ignore the mechanical rotation points of the machine.

The ideal position for the rotation point is always the same as the mechanical rotation point. This approach makes the analysis of the linear data easier and can provide other advantages when calibrating a CMM. One example was found that highlighted the effect of the software using a rotation point that was different than the mechanical rotation point. The effect is clear on the linear data from the compensation map.

Software Error Correction

The error compensation used by coordinate measuring machines does not change the physical shape of the machine. The correction is applied in such a way that the position of the probe stylus is always known based on the errors described in the compensation error table. The software compensation cannot physically remove described errors in the machine but it can estimate the effect those errors will have on the position of the probe stylus.

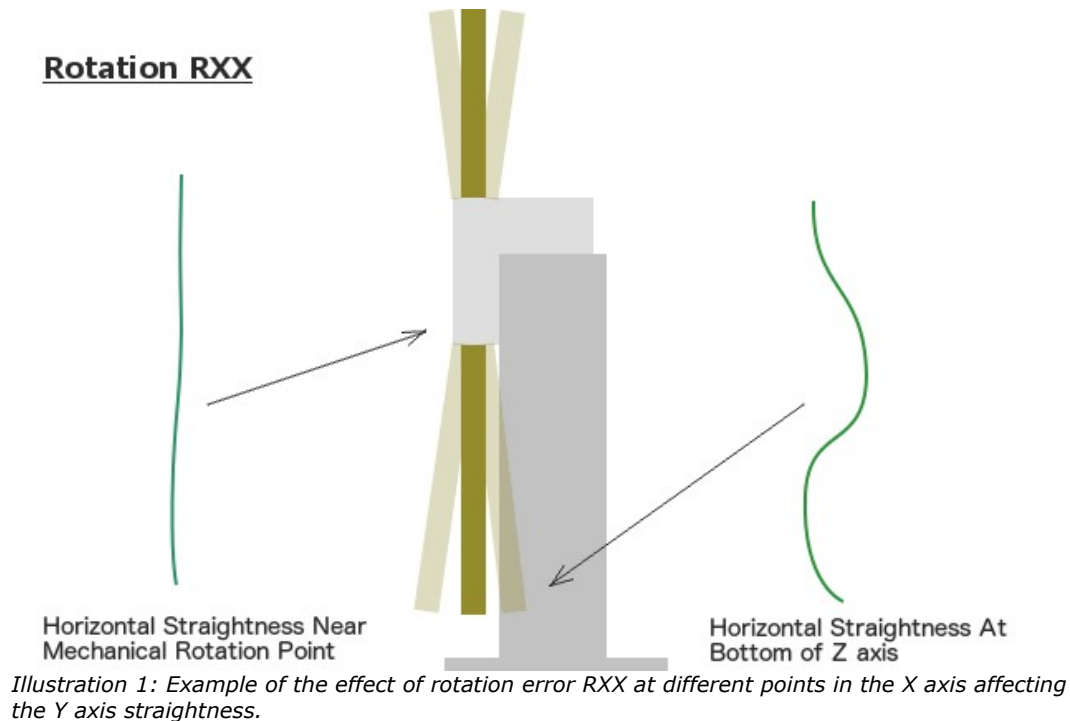
Each axis has six compensation parameters at a minimum. Three compensation parameters are used for angular data (rotations around the X, Y, and Z axis) and three compensation parameters are used for linear data (offset correction in the X, Y, and Z axis direction). Additional parameters may exist for deflection or other non-standard corrections but these are usually layered on top of the six primary parameters.

Practically all manufacturers deal with machine compensation in the same way despite claims to the contrary. One of the areas that does vary between manufacturers is the choice for the placement of the rotation point when interpreting the compensation data. Some manufacturers stick to a generic method that is applied to all machine types while others consider the machine and try to match its mechanical behavior while others use arbitrary rotation points that are tied to data collection from machine calibration. This difference is enough that conversion between compensation map types should be avoided unless the conversion process understands the differences between the map types and updates the data based on the expected differences.

Error Map Rotation Point

Example With X Axis Roll

The easiest way to demonstrate the effect from the position of the error compensation rotation point is to show a practical example. Illustration 1 shows the effect of angular error X roll (RXX) on the horizontal straightness of the X axis of a CMM at two different heights.



The measurement of the horizontal straightness at the center of the rotation point shows virtually no error. The measurement of straightness at the bottom of the Z axis shows the effect of the X axis roll error. These errors physically exist in the machine and will be seen as described if the software error compensation is switched off.

Case 1: Mechanical and Compensation Point Identical

When the mechanical and software rotation points are the same the calculated correction from the angular data matches the physical error of the machine axis. An example showing the calculation for parameter RXX is shown in illustration 2.

Since the software has compensation data describing the X axis roll (RXX) it is able to calculate the actual horizontal position of the Z axis at any Z height. The result is that the straightness error, which was previously measurable with no compensation active, will no longer appear to exist when measuring an artifact like a straight edge. The machine cannot physically remove the error but it can recalculate where the bottom of the Z axis is located. The straightness error seen at the bottom of the Z axis will be identical to the straightness error at the height of the mechanical rotation point.

Since most compensation error maps are interpreted generically a rotation point at the top of the Z is not exactly the same as the rotation center for the X axis roll. The effect of this small difference can be seen by comparing the real X axis horizontal straightness error to the estimated

Error Map Rotation Point

horizontal straightness error. The differences are relatively small but are noticeable.

Rotation RXX



Illustration 2: Calculation of machine error from parameter RXX performed from the position of the mechanical rotation point.

Case 2: Mechanical and Compensation Point Not Identical

When the mechanical and software rotation points are not the same the calculated correction does not match the physical error of the machine axis. An example showing the calculation for the correction of parameter RXX from the bottom of the Z axis is shown in illustration 3.

The mechanical rotation point hasn't changed from the previous example but the software is now calculating the angular correction from the bottom of the Z axis where previously it was calculating from a position near the mechanical rotation center. The effect of the angular compensation is zero at the bottom of the Z axis where the top of the Z axis, near the mechanical rotation point, has the largest correction for the X axis roll (RXX). The result is the straightness error that was previously seen only at the bottom of the Z axis is now seen evenly at all Z heights.

Error Map Rotation Point

Rotation RXX

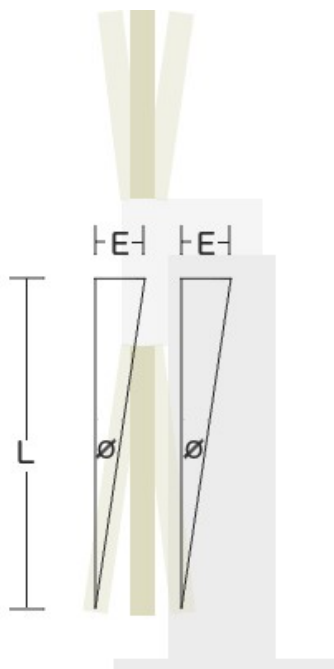


Illustration 3: Calculation of machine error from parameter RXX performed from the bottom of the Z axis. The start of the angular correction is at the moving end of the axis which creates a straightness error at the other end of the axis.

Simulation of Straightness Errors

The effect of using different rotation points of a CMM axis for the angular correction can be simulated. A machine with the dimensions of 1000 x 1000 x 1000 (positive Z axis) was created for the simulation. The angular data for RXX was input with the following expression:

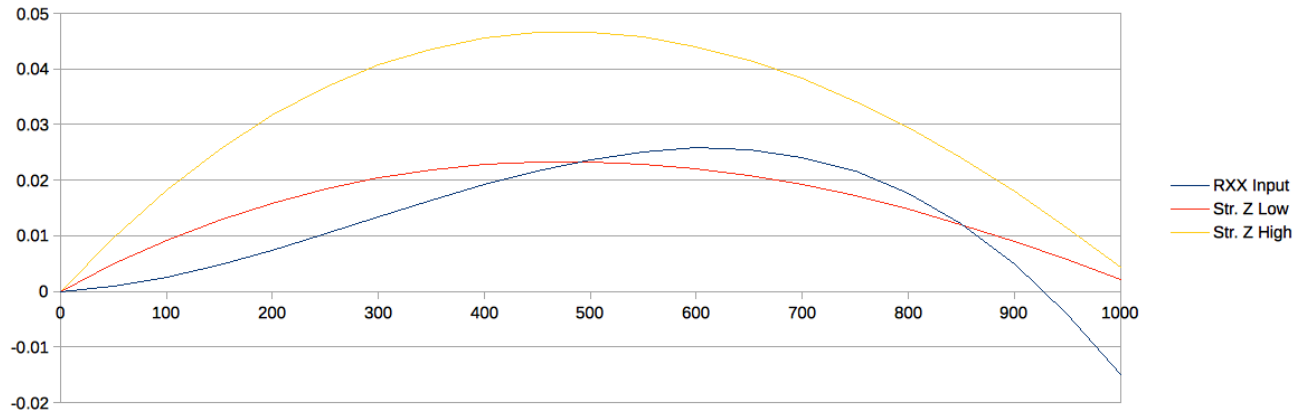
$$R_{XX} = 0.010 * L + 0.127 * L^2 - 0.200 * L^3$$

Where:

L = length in meters.

Two measurements were performed in the X axis of the CMM; one at the top of Z and the other at the bottom. The rotation point was set for the top of the axis and the mechanical rotation is set to the bottom of Z.

Error Map Rotation Point



The straightness at the bottom of the Z axis is as predicted and is a result of the physical rotation of the Z axis around the X. The straightness at the top of the Z axis is significantly larger than that of the bottom which, with compensation applied, will be identical to that at the bottom of the Z axis.

The data was created with the CMM Error Simulator. Version 1.1 or higher is required to perform tests against the mechanical rotation points.

Real World Example

An example when the mechanical and software rotation points do not match was found from a compensation map randomly downloaded from the internet. This compensation map was generated with software that is known to use bottom of the Z axis as the reference starting point for all rotational calculations. The machine kinematic is YXZ and describes a large bridge machine.

The following images shows angular and straightness data separately and combined:

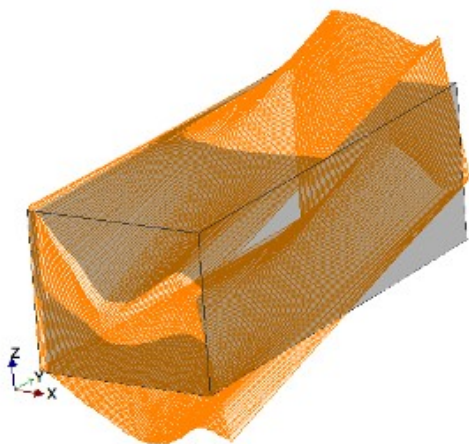


Illustration 4: Graphical view of rotation error RXX

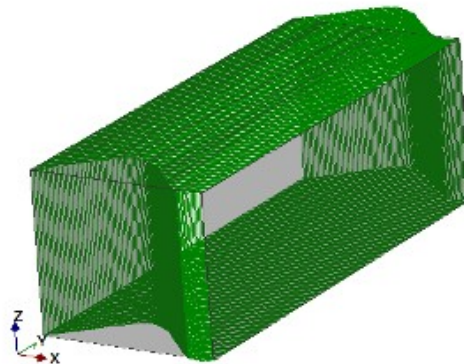


Illustration 5: Graphical view of straightness error LXY

Error Map Rotation Point

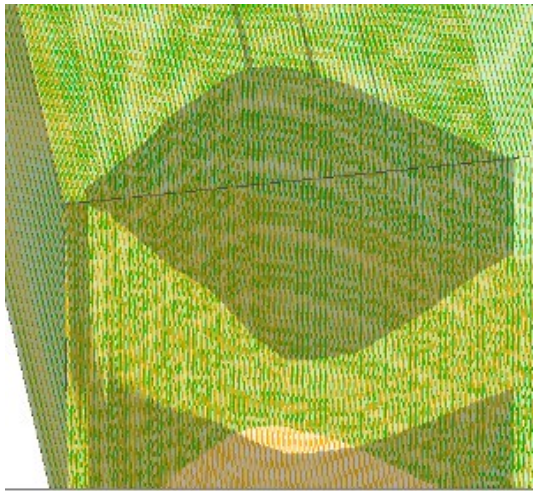


Illustration 6: Direct comparison of the angular RXX to the straightness LXY

The straightness error in this compensation data is clearly tied to the angular roll data. With the math rotation point identical to the mechanical rotation point this kind of relationship would not exist.

As an unrelated comment the data in this particular compensation map looks quite decent. There are certain characteristics considered when evaluating compensation maps and this data appears to be quite good. This is not a comment about the size of the errors contained in the map but the believability of how well the data describes the actual errors of the machine.

The comparison images was created using the compensation viewer program.

Known Issues from Non-Mechanical Rotation Points

The following is a list of known issues from using a non-mechanical rotation point:

- Routines that estimate straightness errors of an axis are no longer reliable without more information than is commonly available.
- The correction in the machine error map ends up larger than what is required. Larger physical errors increase the measurement uncertainty.
- Straightness errors are tied to more of the angular parameters. Angular parameters are more likely to be updated during a calibration without consideration of the affected straightness parameters (*).
- Some compensation maps have very poor control over the limits of the map. If using the end point from one of these maps the corrections will be far worse than simply using the wrong end of the axis.

** Select Calibration Incorporated measures and updates all compensation parameters for all machines when calibrating CMM's. All data is collected and processed simultaneously.*

Compensation Map Conversion

One observation is that compensation maps may be converted from one format to another format

Error Map Rotation Point

without proper consideration of the effects from the conversion. An example of this would be where a machine is purchased that includes a compensation error map collected at the factory but converted into a format that the target inspection software requires. If the two types of compensation data are interpreted differently then the linear data will simply be wrong.

It is theoretically possible to convert the data into different compensation formats if the rotation points are different but this requires a very thorough understanding of how to interpret the compensation data. It is a very error prone approach. Using the method of simply copying the data from one compensation map format into another should always be avoided.

Due to the proprietary nature of most CMM vendors no access to detailed information about the interpretation of the compensation map data will be available. This can further complicate conversion of compensation map from one vendor to another. Most vendors use the same generic routines which means general knowledge combined with basic testing should be sufficient.

Error Map Rotation Point

Revision History

<i>Revision</i>	<i>Date</i>	<i>Reason</i>
1	Aug 6, 2016	Initial Release
2	Aug 7, 2016	Added real world example section.
3	Dec 7, 2019	Document review and update.