Kinematic Axis Order

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Purpose

To describe the significance of the kinematic axis order of a CMM machine. The kinematic order defines how the machine axis are interconnected and is used as part of the machine compensation data to correct for known errors. An incorrect kinematic order means the software is not capable of compensating for the known machine errors properly and may actually increase the measurement error of a CMM.

Software Compensation

Software compensation does not correct the physical errors in the machine but adjusts the axis and scale position based on known machine errors and how the axis are connected to each other.

Software compensation is the common method used for most modern CMM's. Very old CMM's that didn't have the ability to compensate for machine errors relied on manufacturing of very precise bearing guide ways or cleaver mechanical adjustments to remove the physical error of the machine.

The software compensation is separated in two parts, linear and angular. If the physical angular error was mechanically removed from the machine there would be no linear compensation for straightness necessary (scale may require correction). Since the angular errors in the machine are not physically removed there will always be a corresponding straightness error that is directly related to the angular shape.

Linear Compensation Method

Linear compensation includes horizontal straightness, vertical straightness, and scale. Errors in these parameters are compensated easily for each axis. When the machine is at a specific XYZ location the software will look up the linear error entries listed in the compensation map for each axis and directly add this to the raw XYZ coordinate values from the machine controller.

Angular Compensation Method

Angular compensation includes roll, pitch, and yaw errors. These errors are compensated by altering the direction of the next axis that is connected to it. The machine will have the axis physically connected in a specific order and to apply compensation properly the software must also understand how the axis are physically connected to each other.

In order for the software to effectively compensate for angular errors the kinematic order must be known by the software.

Defining Kinematic Axis Order

The kinematic order is defined by methods specific to each implementation of the compensation data. Some compensation maps have a fixed kinematic order and cannot be changed. Some compensation maps will allow selection of the interconnected axis by basic options such as setting the option *Horizontal Arm* or *Vertical Arm* flag and has assumptions about the order of the axis for each configuration. Some compensation maps will allow a complete selection of the kinematic order with options such as XYZ, YXZ, XZY, or YZX.

First Axis

The first axis of the kinematic order is the axis that is part of the base of the machine. This is the axis that doesn't move relative to the table in most cases.

It is easier to visualize directions or vectors when interpreting angular compensation data. The angular compensation data describes angles around specific axis but the vector describes the sum of all the angular data and represents the direction of the next connected axis.

Illustration 1 shows the effect having physical roll error in the X axis of a horizontal arm CMM. As the machine moves along the X axis the roll error changes the direction of the Z axis which is directly connected to the X.

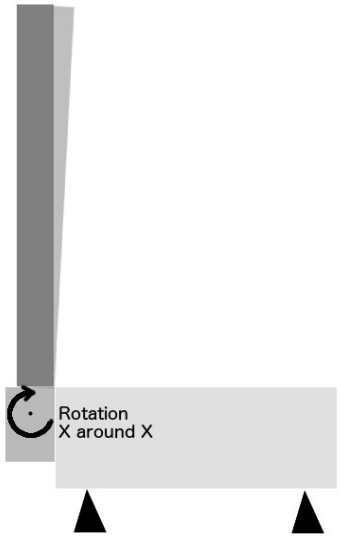

Illustration 1: Horizontal arm X axis showing effect of angular error RXX (rotation of X axis around X).

Second Axis

The second axis of the kinematic order is typically the first *moving* axis of the CMM. The direction of the second axis is based entirely on the angular errors recorded from the compensation data from the first axis. This error will typically change throughout the range of the first axis therefore the direction of the second axis also changes.

The second axis has angular errors independent of the first axis. The angular errors from the second axis, which are based on the position of the second axis relative to this axis reference point, are combined with the angular errors from the first axis to determine the direction of the third axis (Y in this case) of the CMM.

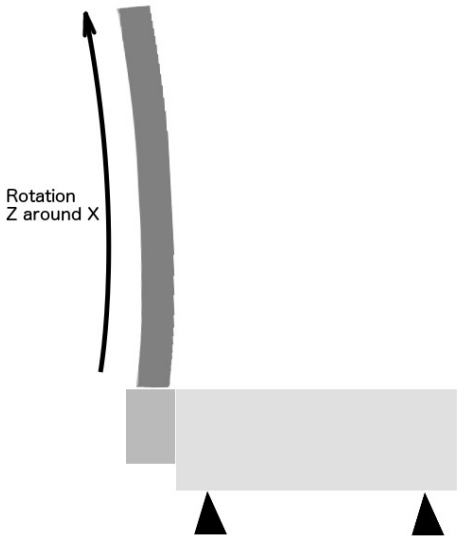

Illustration 2: Horizontal arm Z axis showing effect of angular error RZX (rotation of Z axis around X).

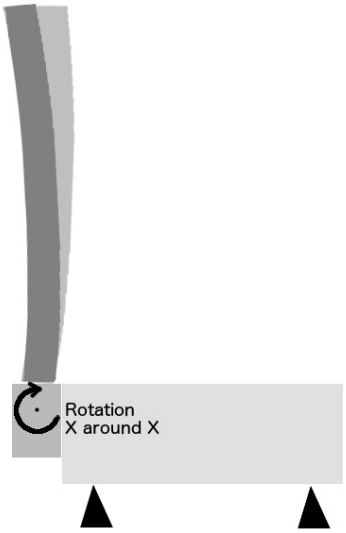

Illustration 3: Horizontal arm Z axis direction is affected by the X axis roll error regardless of Z error.

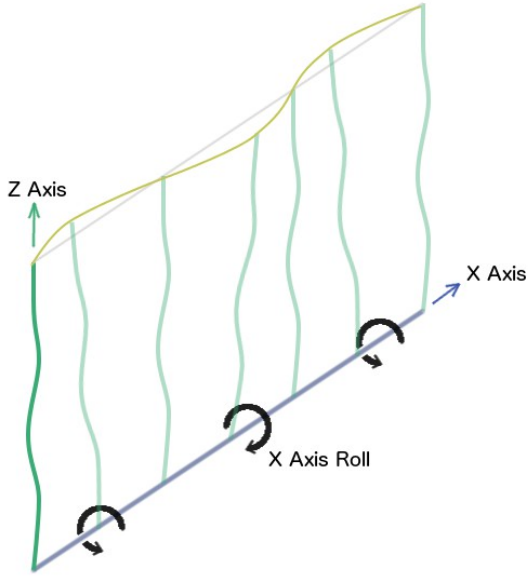

Illustration 4: Horizontal arm Z axis direction influence from X axis. The Z axis has its own angular shape which is added to the effects of the X axis.

Third Axis

The third axis of the kinematic order is typically the second *moving* axis of the CMM. The direction of the third axis is from the sum of the angular errors from the first and second axis of the CMM.

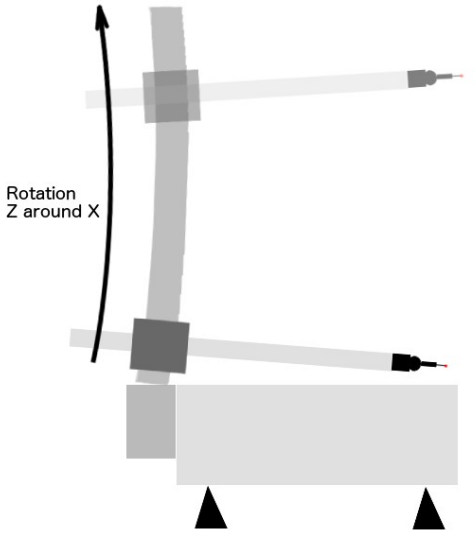

Illustration 5: Horizontal arm Y axis direction based on the sum of all angular errors from the X and Z axis.

The third axis of the CMM (Y in this case) also has angular errors. The sum of the angular errors from all three axis are used to define the direction of the probe sensor. The further the probe sensor is from the end of the third axis the more compensation will be applied based on the sum of all the angular errors in the machine.

Illustration 5 shows a standard probe head mounted to the end of the third axis with a minimal offset. As the offset increases the effect of the changing angular errors at different points in the machine volume will increase.

Kinematic Axis Errors

In the event the kinematic axis is not defined properly then it will be impossible to properly compensate for angular errors in the machine. The math that is used to calculate the real position of the machine will not work properly if the kinematic axis order is incorrect.

An incorrect kinematic axis definition could cause a CMM to actually measure worse with a complete compensation map installed then what would exist with no compensation map data.

Revision History

Revision	*Date*	*Reason*
1	June 8, 2016	Initial Release

