Horizontal Arm Deflection

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Purpose

Horizontal Arm coordinate measuring machines have a unique problem due to their cantilever design. As the arm extends the center of gravity changes resulting in a measurable deflection in the tower of these machines.

This article describes some of the problems related to calibration of horizontal arm coordinate measuring machines and effects of deflection. All manufacturers of horizontal arm CMM's have provisions for dealing with tower deflection as this is a common problem for this type of machine.

Horizontal Arm Coordinate Measuring Machine

A horizontal arm coordinate measuring machine consists of a work table, a tower connected to one side of the table, and an arm that extends from the tower ending with a probe or some other equivalent sensor. The typical axis convention and kinematic chain for these types of machines is XZY where X is parallel to the table, Z is up / down, and Y is across the table.

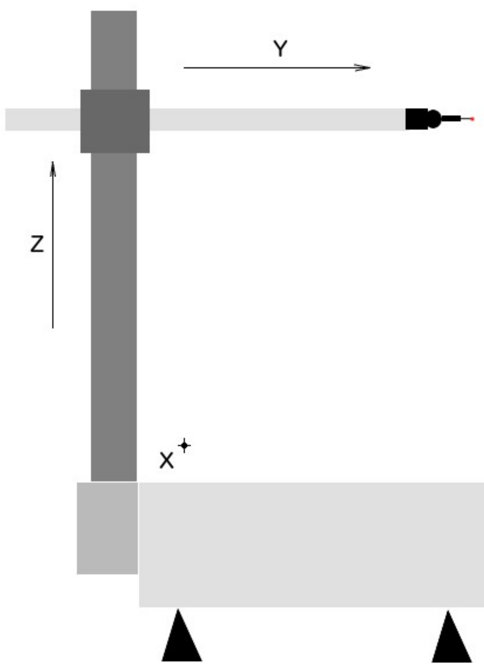

Illustration 1: Typical horizontal arm CMM

Deflection

Deflection of the tower and arm of a horizontal arm CMM is a common problem for this configuration of machine. Deflection may actually be the largest contributing source of errors for this family of CMM's and could be inadvertently changed by the user (i.e. a change of the probe head on the end of the arm, something with a different weight, will affect machine accuracy).

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Vertical arm coordinate measuring machines do not have problems with deflections as each end of the X and Y axis are supported with negligible effects from gravity. The Z axis of a vertical arm CMM is parallel to gravity and therefore does not 'bend' relative to Z position.

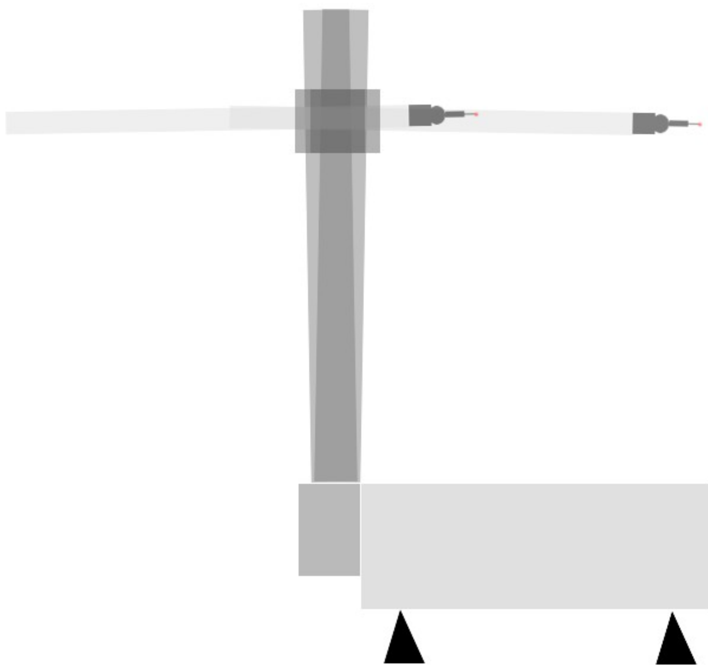

Illustration 2: Deflection of tower and arm as arm is moved from inboard to outboard position

The source of tower deflection of a horizontal arm coordinate measuring machine is primarily from the relatively small mounting area of the X axis as compared to the extent of the Y axis and the need to have the X axis movable and not rigidly attached to the table (a moving table instead of a moving tower version of this machine configuration exists). The Y axis will deflect based on the weight it carries and the size and rigidity of the material used for construction. The Y axis follows any deflection of the tower (which is the primary concern).

Common solutions used by manufacturers to deal with this problem include the following:

- Use of air bearings instead of hard roller bearings at the base of the tower (X axis). Air bearings cover a larger surface area than a typical roller bearing and are more rigid.
- Addition of an upper bearing support to minimize tower deflection.
- Addition of a counter balance for the Y axis. As the Y axis moves in or out the Y counter balance would also move so that the center of gravity does not change as the position of the Y axis changes.

A Y axis counterbalance assembly is a theoretical idea that would help solve the deflection problem of a horizontal coordinate measuring machine. No practical implementation has been observed in the field. Machines with upper bearing supports have been observed.

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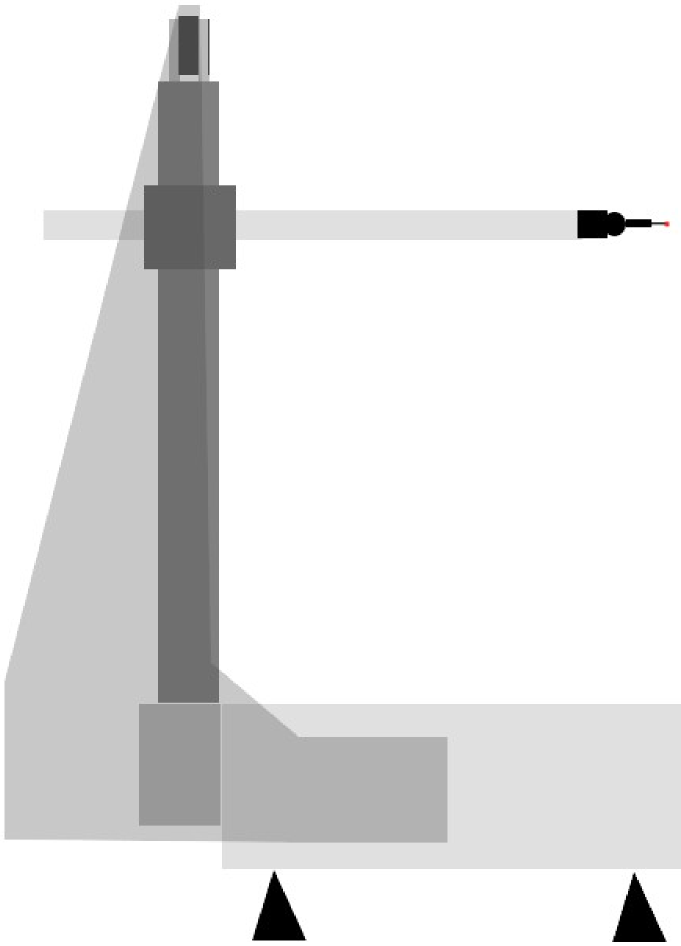

Illustration 3: A horizontal arm coordinate measuring machine with a separate tower supporting structure (bearing surface way) at the top to minimize deflection.

Problems From Deflection

A typical compensation map (eighteen compensation parameters plus three optional squareness parameters) cannot take into account the effect of deflection on measurements. Most manufacturers who do try and compensate for the deflection will do this using additional parameters that are not part of the standard eighteen compensation parameters.

Testing For Deflection

Tower deflection can be checked by placing an electronic level on a surface at the base of the Z axis tower and moving the Y axis through its range. This test should be performed at different positions in the Z axis. Ideally no noticeable rotation or deflection of the tower will be observed.

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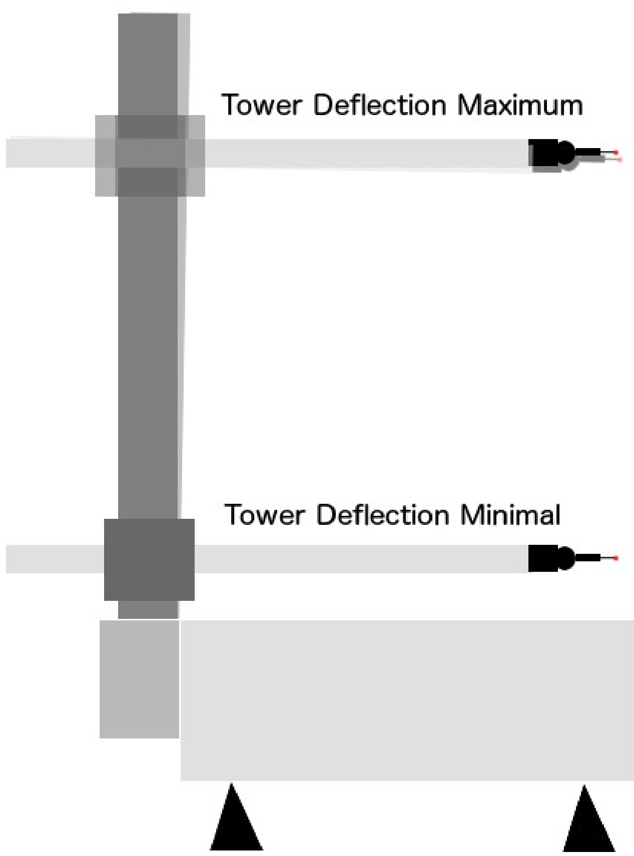
Tower Deflection Effect On Y Measurements

Deflection of the tower will have a 1:1 effect on the measurement of length in the Y axis of the CMM. Assuming the tower deflection is 0.100 mm/m as Y axis is extended through its range then measurements of length along the Y axis at different points along Z axis will directly show this as an error in length. If the Z axis is 2000 mm between test positions the length of error between the top and bottom will be 0.200 mm.

Tower Deflection Effect On Z Measurements

If the tower deflection is constant when tested at different Z positions then the effect on the length in the Z axis will be minimal. In all observed cases the position of the Z axis does result in a different tower deflection so some effect on Z measurements is expected.

If the deflection is large at the top of the tower and smaller or nonexistent at the bottom then the abbe error will be very large when measuring length in the Z axis direction depending on the position in the Y axis. Using the data from the previous example an error of 0.200 mm over a length of 2000 mm with measurements in the Z axis separated by 1000 mm would be expected.



Compensation Methods

Deflection for the tower is not uncommon and most manufacturers of coordinate measuring machines provide parameters specific for this purpose. There is very little correlation in the approaches taken by the different companies in this area so the methods described are generic.

Tower Deflection Of Z Around X

This parameter must be dynamic and based on the position of the Y axis of the coordinate measuring machine. The entries are put into the Z axis data and are a product of this error and the Y axis position in the machine. At Y = 0 no correction is applied. This correction can be tested by measuring a certified length in the Y direction at top and bottom of the Z axis.

Tower Deflection Z Linear

For cases where the tower deflection changes through the range of the Z axis a linear correction in the Z direction of the Y axis must be performed based on the position of both the Z and Y axis. The correction can be tested by measuring a certified test length in the Z direction inboard and outboard of the Y axis.

Observations

This area of compensation is not a shared approach by the different manufacturers of coordinate measuring machines. It has been observed that some manufacturers use a purely generic method to apply deflection compensation (which results in no compensation at the 'zero' point in the volume) while others compensate based on the mechanical rotation point (the actual mechanical rotation point is at the bottom of the tower).

The preferred method is to compensate based on the mechanical rotation point (bottom of the Z axis) resulting in a more natural compensation for the deflection. Using the home position (top of the tower usually) means there is no compensation at the top where there is maximum deflection error and maximum compensation at the bottom where there is minimum deflection error. Although both methods work the preferred method is from the bottom as it doesn't produce unassociated compensation data.

Changes in the probe head or other changes that result in a different amount of weight at the end of the arm will affect the deflection and compensation of the CMM. This can be checked by performing specific tests of length low, high, in, and out. This should not be a common problem but can be an issue if different probe sensors are installed on the machine (i.e. switch from a probing system to a laser scanning system with a significant change in weight can be a problem).

Deflection of the Y axis arm due to gravity should be a constant assuming the weight of the probe on the end of the Y axis is constant. The resulting deflection from the arm bending can be removed by the normal compensation map parameters. These values should not be measured until the tower deflection is compensated otherwise a combination of these two errors will be measured in the linear axis (angular will always be a combination of the two).

Due to the nature of the deflection the linear deflection parameters should be entered as curves in some cases as opposed to gradients. If, for example, the Z axis length when measured at three different points along the Y axis do not show a linear change in length then a compensation curve should be applied to correct for this.

Revision History

Revision	*Date*	*Reason*
1	Sept 20, 2015	Initial Release