Wilcox Associates Inc.
Mathematical Definition of Dimensions
For PC-DMIS

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History of Document Updates

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2.0	June 26, 2006	Updated for V3.7, V4.0, and V41

Abstract

This document describes the mathematical algorithms used to calculate the dimensions of PC-DMIS for all feature types. This document applies to PC-DMIS V3.25, V3.5, V3.7, V4.0 and V4.1.

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1.0 **True Position**

The true position analysis performs a virtual hard-gauge bestfit of the considered feature and datums at material condition. This algorithm works based on allowed degrees of freedom (DOF) as determined by the datums that are selected. There are six possible degrees of freedom for the bestfit -- translation in x, y, or z, and rotation about the x-axis, y-axis, or z-axis. For example, a primary plane datum would be used to control rotation about the x-axis and y-axis, and translation in z. A secondary cylinder datum would control translation in x and y and a tertiary cylinder datum would control rotation about the z-axis. When primary, secondary, and tertiary datums are specified with all at RFS, the true position is fully constrained and no bestfit is performed. When one or more of the datums is at material condition (MMC or LMC), the corresponding degrees of freedom normally constrained by that datum can be used by the bestfit algorithm up to the limit defined by the bonus on that datum of size.

The MEAS position of the considered feature that is reported by PC-DMIS in the true position report is the bestfit position (not the actual measured position). The TP bonus that is reported is the sum of the bonus on the considered feature plus the unused bonus after the bestfit on the datum of size that controls location.

When the considered feature is a cylinder (or other axis feature) or a set of cylinders (or axis features), the TP analysis uses the extrapolated MEAS endpoints of the cylinder(s) to determine the TP deviation and to "fit" the datums. The extrapolated MEAS endpoints are determined by intersecting the MEAS axis with the plane formed by the THEO start point and THEO axis vector to get the MEAS start point, and the plane formed by the THEO end point and THEO axis vector to get the MEAS end point. The user would probably want to select "From WORST end of axis" to report the TP deviation. The "Reference Length" is used for cases where a Projection Zone is desired.

When the datum is a feature set, no material condition is allowed on the datum set and the centroid of the set is the datum position.

Starting with V3.7, the bestfit algorithm attempts to zero the deviation on the considered feature using as much available datum bonus as necessary.

Starting with V4.0, true position can be defined using feature control frames similar to the callouts on drawings. The user must first define which features are to be used as datums by assigning datum letters A, B, C, etc to the datum features. Datums can be specified with material condition. The feature control frames also allow the definition of composite true position with an upper segment PLTZF pattern locating callout and a lower segment FRTZF feature locating callout. The user can specify cylindrical or planar tolerance zones. In addition, the simultaneous evaluation command can be used to evaluate two or more true position callouts simultaneously

(as if they were all one callout) provided that they use the same datums in the same order of precedence with the same material conditions.

In addition, starting with V40, a datum used in a feature control frame can be a set of axial features (e.g., cylinders) all of which are nominally parallel to each other. The feature control frame user in V40 can also specify a compound datum such as A-B where A and B are individual axial datums that are nominally parallel (or coincident).

Starting with V41, the virtual condition of the datums takes into account any true position or orientation tolerance on the datum itself. The bonus on the datum of size at material condition is, therefore, the size bonus plus the true position and/or orientation tolerance refinement.

The PC-DMIS true position bestfit of the datum reference frame is in conformance with ASME (ANSI) Y14.5.

2.0 Coaxiality

The first feature must be a cylinder, line or cone feature. The second feature is used as a datum feature and must be a cylinder, line, cone or circle feature

If no projection distance is specified, the start point and end point of the first feature are used to calculate the coaxiality. The perpendicular distance of each of these points from the datum feature's axis is calculated. These two distances define the max and min values. The coaxiality is twice the max value.

If a projection distance is specified, the start point and the projection distance point of the first feature are used to calculate the coaxiality. The projection distance point is the point which is a projection distance from the first feature's start point along the first feature's vector. The perpendicular distance of each of these points from the datum feature's axis is calculated. These two distances define the max and min values. The coaxiality is twice the max value.

Starting with V40, Coaxiality dimensions can be specified using feature control frames similar to the callouts on drawings. The user must first define which feature is to be used as a datum by assigning datum letters A, B, C, etc to the datum features.

3.0 Concentricity

The first feature must be a sphere (3D concentricity) or a slot, cylinder, cone, or circle (2D concentricity). The second feature is used as a datum feature and must be a cylinder, cone, line, or circle. If there is no datum, the origin and z vector of the current active alignment are used for the datum.

If the first feature is a slot, cylinder, cone, or circle, the perpendicular distance from the centroid of the feature to the datum feature's axis is calculated. The 2D

concentricity is twice this value.

If the first feature is a sphere, the 3D concentricity is calculated as twice the 3D distance of the sphere's centroid from the datum centroid (or active alignment origin if there is no datum).

Starting with V40, Concentricity dimensions can be specified using feature control frames similar to the callouts on drawings. The user must first define which feature is to be used as a datum by assigning datum letters A, B, C, etc to the datum features.

4.0 Orientation

Starting with V40, Orientation dimensions can be specified using feature control frames similar to the callouts on drawings. The user must first define which features are to be used as datums by assigning datum letters A, B, C, etc to the datum features.

4.1 Perpendicularity

The perpendicularity dimension calculates the perpendicularity error of the first feature relative to a datum feature (the second feature). The second feature must be a plane, line, cylinder, or cone. If a second feature is not specified, the working plane is used as the datum.

If the first feature is a cone or a cylinder and no projection distance is specified, the start and end points of the first feature are used to calculate the perpendicularity. If the first feature is a line and no projection distance is specified, all the measure points are used to calculate the perpendicularity.

If the first feature is a cone, cylinder, or a line and a projection distance is specified, the start point and the projection distance point are used to calculate the perpendicularity. The projection distance point is the point which is a projection distance from the first feature's start point along the first feature's vector.

The perpendicularity of a cone, cylinder or line is the minimum diameter straw which is perpendicular to the measured datum feature and contains all the points defined above.

If the first feature is a plane, all the measure points are used to calculated the perpendicularity. The perpendicularity of a plane if the minimum distance between two parallel planes that are perpendicular to the measured datum feature and contain all the measure points.

In V3.7+, if the first feature and/or the datum feature is a feature of size at material condition (MMC or LMC), the bonus on the feature of size is used to evaluate the out-of-tol condition.

4.2 Parallelism

The parallelism dimension calculates the parallelism error of the first feature relative to a datum feature (the second feature). The second feature must be a plane, line, cylinder, or cone. If a second feature is not specified, the working plane is used as the datum.

If the first feature is a cone or a cylinder and no projection distance is specified, the start and end points of the first feature are used to calculate the parallelism. If the first feature is a line and no projection distance is specified, all the measure points are used to calculate the parallelism.

If the first feature is a cone, cylinder, or a line and a projection distance is specified, the start point and the projection distance point are used to calculate the parallelism. The projection distance point is the point which is a projection distance from the first feature's start point along the first feature's vector.

The parallelism of a cone, cylinder or line is the minimum diameter straw which is parallel to the measured datum feature and contains all the points defined above.

If the first feature is a plane, all the measure points are used to calculated the parallelism. The parallelism of a plane if the minimum distance between two parallel planes that are parallel to the measured datum feature and contain all the measure points.

In V3.7+, if the first feature and/or the datum feature is a feature of size at material condition (MMC or LMC), the bonus on the feature of size is used to evaluate the out-of-tol condition.

4.3 Angularity

The angularity dimension calculates the angularity error of the first feature relative to a datum feature (the second feature). The second feature must be a plane, line, cylinder, or cone. If a second feature is not specified, the working plane is used as the datum.

If the first feature is a cone or a cylinder and no projection distance is specified, the start and end points of the first feature are used to calculate the angularity. If the first feature is a line and no projection distance is specified, all the measure points are used to calculate the angularity.

If the first feature is a cone, cylinder, or a line and a projection distance is specified, the start point and the projection distance point are used to calculate the angularity. The projection distance point is the point which is a projection distance from the first feature's start point along the first feature's vector.

The angularity of a cone, cylinder or line is the minimum diameter straw which is at the nominal angle to the measured datum feature and contains all the points defined above.

If the first feature is a plane, all the measure points are used to calculated the angularity. The angularity of a plane if the minimum distance between two parallel planes that are at the nominal angle to the measured datum feature and contain all the measure points.

5.0 Distance

The Distance dimension evaluates the distance between two features.

5.1 2-Dimensional

If the user selects a distance perpendicular or parallel to an axis of the workplane, then the 2D distance is the distance from the centroid of the first feature projected into the workplane to the centroid of the second feature projected into the workplane measured parallel or perpendicular to the selected axis of the workplane.

If the user selects a distance perpendicular or parallel "To Feature", then the third feature is used as a datum whose vector is used to define the direction in the workplane along which the distance between the first two features is calculated. If the datum feature is a plane, then the direction vector is defined by the line created from the intersection of the datum plane and the workplane. The 2D distance is the distance from the centroid of the first feature projected into the workplane to the centroid of the second feature projected into the workplane measured parallel or perpendicular to the direction vector defined by the datum feature.

If the user selects nothing in the "Relationship" group on the dialog (i.e., neither parallel nor perpendicular to either an axis or a feature), then the 2D distance is calculated cenroid to centroid in the workplane

5.2 3-Dimensional

Spheres, points and sets are treated as points. Slots, cylinders, cones, lines, circles and ellipses are treated as lines.

If both features are point type features, then the 3D distance is the shortest distance from point to point.

If one feature is a line type feature and the other is a point type feature, then the 3D distance is the shortest distance from the point type feature to the line (or centerline).

If both features are line type features, the 3D distance is the shortest distance from the centroid of the first line to the second line. PC-DMIS also reports the min and max distance of the measure points of the first line to the second line.

If one feature is a plane and the other is a line type feature, the 3D distance is the shortest distance from the centroid of the line to the plane. PC-DMIS also reports the min and max distance of the measure points of the line to the plane.

If one feature is a plane and the other is a point type feature, the 3D distance is the shortest distance from the point type feature to the plane.

If both features are planes, the 3D distance is the shortest distance from the centroid of the first plane to the second plane. PC-DMIS also reports the min and max distance of the measure points of the first plane to the second plane.

6.0 Angle

The Angle dimension evaluates the angle between two features or between a feature and an axis of the current active alignment.

6.1 2-Dimensional

If two features are selected, the 2D angle dimension evaluates the angle between the two features in the current workplane. If only one feature is selected, the 2D angle dimension evaluates the angle between the feature and the selected axis of the current active alignment (X or Y) in the workplane.

6.2 3-Dimensional

If two features are selected, the 3D angle dimension evaluates the angle between the two features. If only one feature is selected, the 3D angle dimension evaluates the angle between the feature and the selected axis of the current active alignment (X, Y, or Z).

7.0 Form

7.1 Roundness

Roundness can be calculated for circles, cylinders, spheres, and cones. The roundness is based on the least squares solution of the feature. The radial deviation of each measure point is calculated using the measured radius of the feature. For cones, the measured radius of the cone at the height of a given measure point is used to calculate the deviation for that point. The difference

between max and min deviation is the roundness tolerance.

Starting with V40, roundness has been separated into circularity and cylindricity when specified using feature control frames. The evaluation using feature control frames finds two concentric circles or cylinders that contain all the measure points and are as close together as possible. This algorithm conforms with the specifications of ASME(ANSI) Y14.5 and ISO1101. (Note that when using legacy form dimensions in V40+, the least squares min-max algorithm is still used.)

7.2 Straightness

The straightness of a line feature is a 2D calculation in the current workplane if the line is a 2D line. In this case, the 2D deviation of each measure point from the measured line in the workplane is calculated. If the line is a 3D line, the 3D deviation of each measure point from the measured line is calculated. The difference between the max and min deviation is the straightness tolerance.

7.3 Flatness

Flatness is based on the least squares solution of the plane. The flatness of a plane is calculated as the deviation of each measure point from the measured plane. The difference between the max and min deviation is the flatness tolerance.

8.0 Profile

For versions V3.25 and V3.5, the only profile dimension available is surface profile. For V3.7+, the user can select either Line Profile (for 2D features such as lines and curves), or Surface Profile for 3D features.

Starting with V4.0, line and surface profile can be defined using feature control frames similar to the callouts on drawings. The user must first define which features are to be used as datums by assigning datum letters A, B, C, etc to the datum features. Datums can be specified with material condition. For surface profile a bestfit algorithm is used which minimizes the profile deviation by using the available datum bonus. The feature control frames also allow the definition of composite profile with an upper and lower segment callout. In addition, the simultaneous evaluation command can be used to evaluate two or more surface profile callouts simultaneously (as if they were all one callout) provided that they use the same datums in the same order of precedence with the same material conditions.

8.1 Line

The line profile is available only with V3.7+. This profile dimension is suitable for 2D features such as lines and curves. The line profile is calculated by computing the deviation of each actual measure point from the corresponding theoretical measure point in the direction of the theoretical vector for that point. Results can be reported for form only or form and location. Form only will calculate the measured profile tolerance value from max-min deviation, and the profile dimension will check the measured value to see if it is out of tolerance. The form and location will calculate the measured profile tolerance value from max-min deviation for information purposes, but in checking whether or not it is out of tolerance it compares max to the plus tol, and compares min to the minus tol. Both of them must be in tolerance.

When form only is selected, the user also has the option of doing a 2D least squares bestfit of the theoretical and actual measure points before the profile form is calculated. Of course, the user also has the option of doing a 2D bestfit alignment before the profile dimension if a bestfit other than least squares is desired.

8.2 Surface

Any feature can be selected for a surface profile dimension. The surface profile is calculated by computing the deviation of each actual measure point from the corresponding theoretical measure point in the direction of the theoretical vector for that point. Results can be reported for form only or form and location. Form only will calculate the measured profile tolerance value from max-min deviation, and the profile dimension will check the measured value to see if it is out of tolerance. The form and location will calculate the measured profile tolerance value from max-min deviation for information purposes, but in checking whether or not it is out of tolerance it compares max to the plus tol, and compares min to the minus tol. Both of them must be in tolerance.

Starting with V40, the user can report the profile deviation as 2 times the max deviation (for form and location) by setting the registry variable Option\UseISOCalculations.

For V3.7+, when form only is selected, the user also has the option of doing a 3D least squares bestfit of the theoretical and actual measure points before the profile form is calculated. Of course, the user also has the option of doing a 2D bestfit alignment before the profile dimension if a bestfit other than least squares is desired.

9.0 Runout

The runout dimension determines the runout of the first feature with respect to the second feature (i.e., the second feature becomes the datum feature). If only one feature is selected, the origin of the current active alignment and the workplane vector define the datum feature. The text in the Edit window for the datum feature will read "THE ORIGIN".

This option works for circles, cones, cylinders, spheres, and planes. This dimension type is considered one sided, meaning a single positive value tolerance is applied.

The runout for circles, cones, and cylinders is the difference between the max and min radial deviation of the measure points from the datum axis. The runout for spheres is the difference between the max and min radial deviation of the measure points from the datum origin. The radial deviation of circles, cylinders and spheres is based on the measured radius of the feature. The radial deviation of cones is based on the radius at the cone height of each measure point using the measured angle of the cone.

The runout for planes is the difference between the max and min deviation of the measure points from the plane formed by the feature plane's measured centroid and the datum vector.

For cylinders, cones, spheres and planes, the reported runout is the total runout. For circles, the reported runout is circular runout.

10.0 Symmetry

The symmetry dimension calculates the symmetry of a set of points with a datum feature, or two opposing lines with a datum feature.

- If the first feature is a *set*, the second feature that is entered is the datum feature and must be either a plane or a line.

- If the first feature is a *line*, the second feature must also be a line and the third feature that is entered is the datum feature. In this case the third feature must be a plane or a line. This dimension type is considered one sided, meaning a single positive value tolerance is applied.

- If the third feature is a *plane*, the symmetry algorithm attempts to find a line on that plane that represents the datum. To find the correct line, it intersects (or crosses) the chosen plane with the work plane. For this reason, you should ensure that you are using the correct work plane.

Because of the way the symmetry is defined, PC-DMIS limits the features that can be used for the symmetry dimension. Since the points must be equally arranged about the datum in order to find midpoints between them, you must either select a feature set with alternating points or two opposing lines with the same number of points. The symmetry tolerance is twice the maximum deviation of the midpoints from the datum.