

Fast checking of CMM geometry with a patented tool

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Résumé. L'utilisation d'une Machine à Mesurer Tridimensionnelle (MMT) requiert une bonne connaissance des défauts géométriques de la machine, afin d'obtenir des résultats fiables. Les essais de réception ou l'autocontrôle à partir de la série de normes ISO 10360 sont suffisants dans certains cas, mais ne permettent pas, en cas d'erreurs de mesure, de remonter au paramètre géométrique défaillant.

Un nouvel outil, construit à partir d'éléments étalonnés, permet d'obtenir une information globale sur la géométrie de la MMT, et ne nécessite que peu de temps de mesure pour réaliser une image des défauts géométriques de la MMT.

Nous présentons ce nouvel outil, breveté, ainsi qu'un exemple d'utilisation.

Introduction

Acceptance tests or recertification tests based on ISO 10360 standards [1] give results which must be within a tolerance to pass the test. If some results are out of tolerance, the CMM has to be calibrated. This operation can take a long time, because the cause of the defect is generally unknown.

A ball bar test [2] [3] can give some information about rotations of the CMM, but it is time consuming, and the result isn't linked to the meter definition.

In fact, the new tool presented here resolves those little defects, and facilitates the wrong parameter identification, so that the calibration required is less demanding than a total calibration.

Starting from geometrical defects of a CMM, we present this new tool and the results of a demonstration.

1. Retrieval about CMM geometry

Geometrical defects generated by the CMM manufacturing are compensated with a matrix, which is usually built with an interferometer and its reflectors. The real displacements of the CMM are measured with the interferometer, and the difference between the CMM readings and the interferometer ones are included in the compensation matrix, so that the measurements can be accurate. Rotations during displacements can be measured with an electronic level.

Along each axis, the matrix compensates the trueness of the scale, the straightness of the displacement perpendicularly of it (which are linear parameters) and the roll, the pitch and the yaw (which are angular parameters of rotation) (fig. 1).

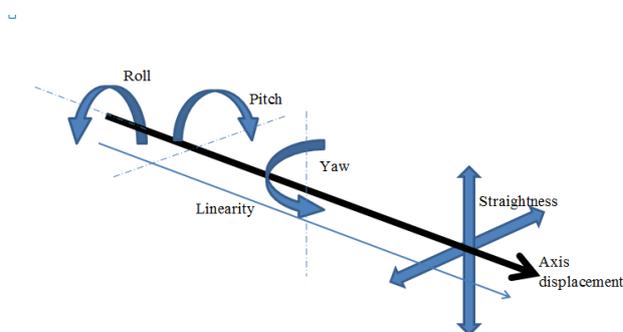


Figure 1: defects along an axis

The matrix contains the compensation values measured along each axis with a step (fig.2). The CMM interpolates its position from a math function between steps, so that each measured point can be compensated.

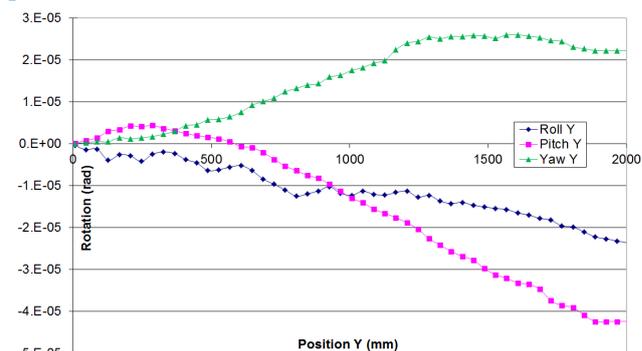


Figure 2 : graphical representation of the Y axis compensation values (rotations only)

In addition to those, the three values of perpendicularity between axes, two by two, are included in the matrix (fig.3).

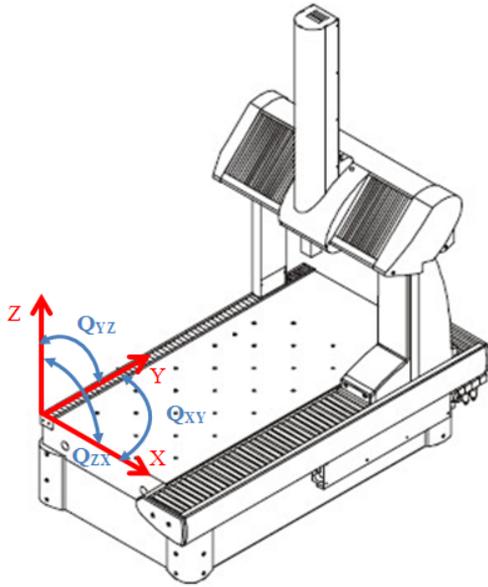


Figure 3: axes and perpendicularity

Those values are considered as constant values, they can be integrated in rotation values or calculated as straightness defect, and add to a linear compensation, it depends on the CMMs manufacturer. All those compensated values are often called “21 parameters matrix”. Each term of the matrix is really accurate at the moment of matrix creation. All temperature variations, vibrations or probe collisions (...) can alter CMM geometry, without any change on the matrix. For this reason, it’s essential to check regularly the compensation validity.

The compensation of geometrical defects during the measurement is calculated from the method of small displacements torsor [4]. During the movement of an axis, the two others axes are considered as fixed. This allows writing the geometrical defect equation as the sum of defects from each axis.

In our case (fig. 4), the calculation begins by the displacement of the Y axis, then the X axis and then the Z axis:

$$\begin{aligned} \overrightarrow{E_Y(P)} &= \overrightarrow{E_Y(O_1)} + \overrightarrow{W_Y} \wedge \overrightarrow{O_1P} \\ \overrightarrow{E_X(P)} &= \overrightarrow{E_X(O_2)} + \overrightarrow{W_X} \wedge \overrightarrow{O_2P} \\ \overrightarrow{E_Z(P)} &= \overrightarrow{E_Z(O_3)} + \overrightarrow{W_Z} \wedge \overrightarrow{O_3P} \end{aligned}$$

$\overrightarrow{E_i(O_j)}$ represents linear defects of the i axis, noted L_{ix} , L_{iy} , L_{iz} afterward, and $\overrightarrow{W_i}$ represents rotation defects R_{ix} , R_{iy} , R_{iz} (fig. 5).

$\overrightarrow{O_jP}$ is the vector between a particular point of the j axis and the probe center ball, so it’s the sum of scale readings (P_x, P_y, P_z) and probe offsets (T_x, T_y, T_z).

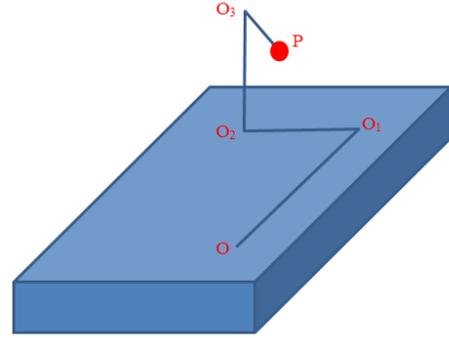


Figure 4: moves representation

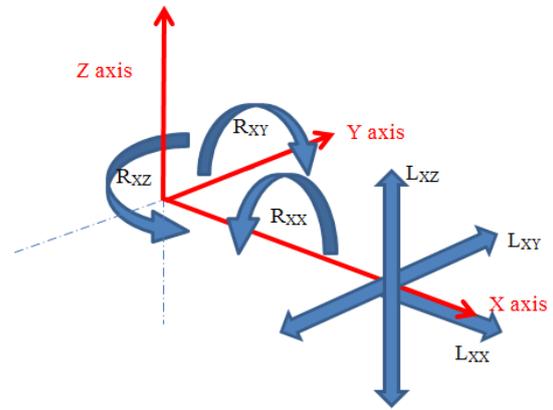


Figure 5: defect explanation along the X axis

Those cross products give the following contribution of each axis displacement.

- Contribution of the Y axis displacement

$$\begin{aligned} \overrightarrow{E_Y(P)} &= [L_{YX} + R_{YY} \cdot (P_Z + T_Z) - R_{YZ} T_Y] \vec{X} + [L_{YY} \\ &+ R_{YZ} \cdot (P_X + T_X) - R_{YX} (P_Z + T_Z)] \vec{Y} \\ &+ [L_{YZ} + R_{YX} \cdot T_Y - R_{YY} (P_X + T_X)] \vec{Z} \end{aligned}$$

- Contribution of the X axis displacement

$$\begin{aligned} \overrightarrow{E_X(P)} &= [L_{XX} + R_{XY} \cdot (P_Z + T_Z) - R_{XZ} T_Y] \vec{X} \\ &+ [L_{XY} + R_{XZ} T_X - R_{XX} (P_Z + T_Z)] \vec{Y} \\ &+ [L_{XZ} + R_{XX} \cdot T_Y - R_{XY} T_X] \vec{Z} \end{aligned}$$

- Contribution of the Z axis displacement

$$\begin{aligned} \overrightarrow{E_Z(P)} &= [L_{ZX} + R_{ZY} \cdot T_Z - R_{ZZ} T_Y] \vec{X} + [L_{ZY} + R_{ZZ} \cdot T_X \\ &- R_{ZX} T_Z] \vec{Y} + [L_{ZZ} + R_{ZX} \cdot T_Y - R_{ZY} T_X] \vec{Z} \end{aligned}$$

From those three equations, the probe position is compensated along each axis using those parameters:

$$\begin{aligned} C_X &= L_{XX} + L_{YX} + L_{ZX} + R_{YY} \cdot (P_Z + T_Z) \\ &- R_{YZ} T_Y + R_{XY} \cdot (P_Z + T_Z) - R_{XZ} T_Y + R_{ZY} \cdot T_Z - R_{ZZ} T_Y \\ C_Y &= L_{XY} + L_{YY} + L_{ZY} + R_{YZ} \cdot (P_X + T_X) - R_{YX} (P_Z + T_Z) \\ &+ R_{XZ} T_X - R_{XX} (P_Z + T_Z) + R_{ZZ} \cdot T_X - R_{ZX} T_Z \end{aligned}$$

$$C_Z = L_{XZ} + L_{YZ} + L_{ZZ} + R_{YX} \cdot T_Y - R_{YY} (P_X + T_X) + R_{XX} \cdot T_Y - R_{XY} T_X + R_{ZX} \cdot T_Y - R_{ZY} T_X$$

The perpendicularity between:

- X and Z is included in the straightness L_{ZX} ,
- X and Y is included in the straightness L_{XY} ,
- Y and Z is included in the straightness L_{ZY} .

It can be noted that:

- $L_{XX}, L_{XY}, L_{XZ}, R_{XX}, R_{XY}, R_{XZ}$ depend only on the X axis displacement,
- $L_{YX}, L_{YY}, L_{YZ}, R_{YX}, R_{YY}, R_{YZ}$ depend only on the Y axis displacement,
- $L_{ZX}, L_{ZY}, L_{ZZ}, R_{ZX}, R_{ZY}, R_{ZZ}$ depend only on the Z axis displacement.

2. Description of the patented new tool

Checking the CMM geometry needs to measure some known objects, linked to the meter definition, so that each parameter can be verified. It can be done with an interferometer, which is a long and expensive method, or with a step gauge, which is also long and expensive [5].

In order to check the CMM in a short time, we propose a gauge assembly, constructed with block gauges and cylinder gauges, in the shape of a triangle [6] (fig.6). Each block gauge has contact with a cylinder at each end, so the length of each side of the triangle is known, with a calculated uncertainty. Angles can be calculated by trigonometry, the uncertainty on angles is calculated by the Monte-Carlo method. This tool allows only a global check of linear and rotation defects, no local ones. Its assembly is totally described in the patent [6].



Figure 6: two-dimensional standard

3. Calculation of residual defects using the standard

The assembly can be measured horizontally or vertically, the hypotenuse parallel to a CMM axis. The first step is a plane measurement, to define the level for circles measurements. Then, circles can be measured, and distance between them calculated, and compared to the nominal length.

In order to demonstrate the check, we propose some hypotheses:

- If the measurement is done horizontally, the probe axis is vertical. In this case, we consider that T_X and T_Y are null.

- If the measurement is done vertically, the probe axis is horizontal. In this case, we consider that T_Z is null, and one of T_X and T_Y can be null.

3.1 Linear measurements in the XY plane

This application is done with the hypotenuse parallel to the X axis (fig. 7). In this case, the height of the triangle (normal to the hypotenuse, by definition) is parallel to the Y axis, and both others sides are along diagonals.

Equation C_X becomes:

$$C_X = L_{XX} + L_{YX} + L_{ZX} + R_{YY} \cdot (P_Z + T_Z) + R_{XY} \cdot (P_Z + T_Z) + R_{ZY} \cdot T_Z$$

The distance between two points P1 and P2 can be calculated from:

$$\overrightarrow{P_1 P_2} = \overrightarrow{P_1 O} + \overrightarrow{OP_2} = \overrightarrow{OP_2} - \overrightarrow{OP_1}$$

The compensation between both points is the difference of compensations at each point. The difference between measured values and standard values can be assimilated as a compensation defect, which can be calculated.

The compensation of a distance between two circle centers aligned along the X axis, ($C_{X2} - C_{X1}$), allows to eliminate values which don't depend on X displacement, so :

$$C_{X2} - C_{X1} = L_{XX}\{X_2\} - L_{XX}\{X_1\} + (R_{XY}\{X_2\} - R_{XY}\{X_1\})(P_Z + T_Z)$$

It represents the trueness defect on the distance between X_1 and X_2 , in addition to the X pitch effect.

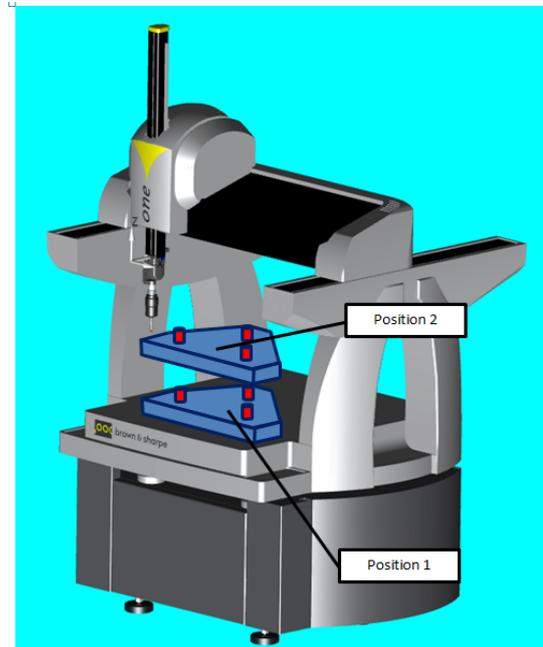


Figure 7: Positioning on the XY plane

If a second position is measured, higher than the first one, but aligned on it, the trueness defect is eliminated, and the pitch difference has the same value in both positions, then the calculation becomes:

$$(C_{X2} - C_{X1}) - (C_{X4} - C_{X3}) = (R_{XY}\{X_2\} - R_{XY}\{X_1\})(P_{Z2} - P_{Z1})$$

It represents the X pitch defect on a height of (Z_2-Z_1) . It allows also calculating the trueness of the X axis.

Along the Y axis, the method is the same. The greatest difference is the calculation along the height of the triangle, which is a calculated value, instead of a measured one.

Equation C_Y becomes:

$$C_Y = L_{XY} + L_{YY} + L_{ZY} + R_{YZ} \cdot P_Z + T_Z - R_{XX}(P_Z + T_Z) - R_{ZX}T_Z$$

Then the compensation on the height is:

$$(C_{Y2} - C_{Y1}) = L_{YY}\{Y_2\} - L_{YY}\{Y_1\} + (R_{YZ}\{Y_2\} - R_{YZ}\{Y_1\})P_X - (R_{YX}\{Y_2\} - R_{YX}\{Y_1\})(P_Z + T_Z)$$

This is the sum of trueness defect along the Y axis on the height, with the effects of the Y yaw and the Y pitch.

With the second position, the calculation is:

$$(C_{Y2} - C_{Y1}) - (C_{Y4} - C_{Y3}) = -(R_{YX}\{Y_2\} - R_{YX}\{Y_1\})(P_{Z2} - P_{Z1})$$

It allows calculating the Y pitch.

3.2 Linear measurements in the YZ plane

In this case, the standard is positioned vertically, the hypotenuse parallel to the Y axis. The height of the triangle is parallel to the Z axis. Measurements must be done on the left side and on the right side of the CMM, without any rotation of the head between both sides. The probing system is parallel to the X axis (fig. 8).



Figure 8: positioning on the YZ plane

Taking into account the hypotheses made in section 1, the equation C_Y becomes:

$$C_Y = L_{XY} + L_{YY} + L_{ZY} + R_{YZ} \cdot (P_X + T_X) - R_{YX}(P_Z) + R_{XZ}T_X - R_{XX}(P_Z) + R_{ZZ} \cdot T_X$$

The distance between two circles aligned along the Y axis isn't affected by L_{XY} , L_{ZY} , R_{XZ} , R_{XX} or R_{ZZ} (X and Z values don't change during the measurement), so:

$$C_{Y2} - C_{Y1} = L_{YY}\{Y_2\} - L_{YY}\{Y_1\} + (R_{YZ}\{Y_2\} - R_{YZ}\{Y_1\}) \cdot (P_X + T_X)$$

In a second position along the X axis, parallel to the first, the difference between both measurements is:

$$(C_{Y2} - C_{Y1}) - (C_{Y4} - C_{Y3}) = (R_{YZ}\{Y_2\} - R_{YZ}\{Y_1\}) \cdot (P_{X2} - P_{X1})$$

It gives the value of the global Y yaw R_{YZ} on a length of $P_{X2} - P_{X1}$.

With those equations, R_{YZ} is known, so the linear defect L_{YY} can be calculated.

In those positions, the height of the triangle is along the Z axis. The equation C_Z (compensation along Z) becomes:

$$C_Z = L_{XZ} + L_{YZ} + L_{ZZ} + R_{YY}(P_X + T_X) - R_{XY}T_X - R_{ZY}T_X$$

The compensation on the height is:

$$(C_{Z2} - C_{Z1}) = L_{ZZ}\{Z_2\} - L_{ZZ}\{Z_1\} - (R_{ZY}\{Z_2\} - R_{ZY}\{Z_1\})T_X$$

A third position in the YZ plane is needed, with a longer tip than the first one. The standard must be moved so that the CMM stays in the same position on three axes.

The difference between both positions is:

$$(C_{Z2} - C_{Z1}) - (C_{Z4} - C_{Z3}) = (R_{ZY}\{Z_2\} - R_{ZY}\{Z_1\})(T_{X2} - T_{X1})$$

It allows calculating the Z yaw R_{ZY} , so L_{ZZ} can be known.

3.3 Linear measurements in the ZX plane

In this application, the standard is still positioned vertically, the hypotenuse along the X axis. T_x and T_z are null, T_y is the tip offset along Y.

Equation C_X becomes:

$$C_X = L_{XX} + L_{YX} + L_{ZX} + R_{YY} \cdot (P_Z) - R_{YZ}T_Y + R_{XY} \cdot (P_Z) - R_{XZ}T_Y - R_{ZZ}T_Y$$

The distance between two circles aligned along the X axis is:

$$C_{X2} - C_{X1} = L_{XX}\{X_2\} - L_{XX}\{X_1\} - (R_{XZ}\{X_2\} - R_{XZ}\{X_1\})T_Y$$

A second position in the ZX plane is needed, with a longer tip than the first one. The standard must be moved so that the CMM stays in the same position on three axes.

$$(C_{X2} - C_{X1}) - (C_{X4} - C_{X3}) = -(R_{XZ}\{X_2\} - R_{XZ}\{X_1\})(T_{Y2} - T_{Y1})$$

L_{XX} is known, so the X yaw R_{XZ} can be calculated directly.

Applying the same method along the Z axis, C_Z becomes:

$$C_Z = L_{XZ} + L_{YZ} + L_{ZZ} + R_{YX} \cdot T_Y - R_{YY}(P_X) + R_{XX} \cdot T_Y + R_{XZ} \cdot T_Y$$

The height of the triangle is compensated by:

$$C_{Z2} - C_{Z1} = L_{ZZ}\{Z_2\} - L_{ZZ}\{Z_1\} + R_{ZX} \cdot T_Y$$

so:

$$(C_{Z2} - C_{Z1}) - (C_{Z4} - C_{Z3}) = (R_{ZX})(T_{Y2} - T_{Y1})$$

This allows calculating the Z pitch R_{ZX} .

3.4 Measurements along diagonals

In this chapter, the previous measurements are treated, taking into account all the known results.

3.4.1 Diagonals in the XY plane

The compensation along a diagonal in the XY plane is calculated from C_X and C_Y equations.

$$C_X = L_{XX} + L_{YX} + L_{ZX} + R_{YY} \cdot (P_Z + T_Z) + R_{XY} \cdot (P_Z + T_Z) + R_{ZY} \cdot T_Z$$

$$C_Y = L_{XY} + L_{YY} + L_{ZY} + R_{YZ} \cdot P_X - R_{YX}(P_Z + T_Z) - R_{XX}(P_Z + T_Z) - R_{ZX}T_Z$$

The contribution of each axis defect on the distance between two circles P_1 and P_3 along a CMM diagonal is:

$$(C_{P3X} - C_{P1X}) = L_{XX}\{X_3\} - L_{XX}\{X_1\} + L_{YX}\{Y_3\} - L_{YX}\{Y_1\} + (R_{XY}\{X_3\} - R_{XY}\{X_1\}) + R_{YY}\{Y_3\} - R_{YY}\{Y_1\} \cdot (P_Z + T_Z)$$

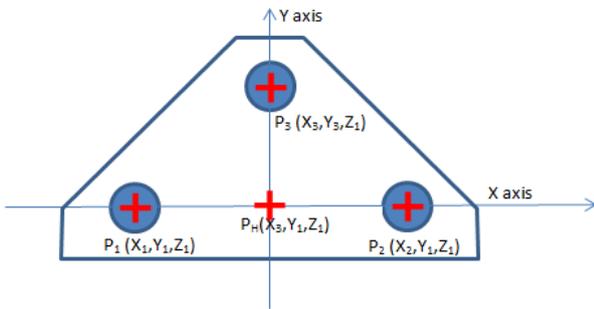


Figure 9: Diagonals in the XY plane

The compensation along diagonals should be calculated from linear compensations, using Chasles relation and Pythagoras. The calculation uses point P_H (fig. 9), comparing along the X axis the compensation on P_1P_3 and P_1P_H , and along the Y axis the compensation on P_1P_3 and P_HP_3 . The difference between both ways of calculation is the effect of a diagonal move.

The X linear effect subtracts from this result, it gives:

$$(C_{P3X} - C_{P1X}) - (C_{PHX} - C_{P1X}) = L_{YX}\{Y_3\} - L_{YX}\{Y_1\} + (R_{YY}\{Y_3\} - R_{YY}\{Y_1\}) \cdot (P_Z + T_Z)$$

with $(C_{P3X} - C_{P1X})$ which represents the projection along the X axis of the measured defect, using the cosine of standard angle.

The same approach on the Y axis allows writing the defect on the diagonal P_1P_3 :

$$C_{P3Y} - C_{P1Y} = L_{XY}\{X_3\} - L_{XY}\{X_1\} + L_{YY}\{Y_3\} - L_{YY}\{Y_1\} - (R_{YX}\{Y_3\} - R_{YX}\{Y_1\}) + R_{XX}\{X_3\} - R_{XX}\{X_1\} \cdot (P_Z + T_Z) + (R_{YZ}\{Y_3\}P_{X3} - R_{YZ}\{Y_1\}P_{X1})$$

Subtracting the linear defect, it gives:

$$(C_{P3Y} - C_{P1Y}) - (C_{P3Y} - C_{PHY}) = L_{XY}\{X_3\} - L_{XY}\{X_1\} + (R_{XX}\{X_3\} - R_{XX}\{X_1\})(P_Z + T_Z) + R_{YZ}\{Y_1\}(P_{X3} - P_{X1})$$

with $(C_{P3Y} - C_{PHY})$ which represents the projection along the Y axis of the measured defect, using the sine of standard angle.

Applying the same reasoning on the higher position of the standard, it allows us to discard straightness and the Y yaw defects, which do not depend on the height:

$$(C_{P6X} - C_{P4X}) - (C_{PH2X} - C_{P4X}) - (C_{P3X} - C_{P1X}) + (C_{PHX} - C_{P1X}) = (R_{YY}\{Y_3\} - R_{YY}\{Y_1\}) \cdot (Z_2 - Z_1)$$

and:

$$(C_{P6Y} - C_{P4Y}) - (C_{P6Y} - C_{PH2Y}) - (C_{P3Y} - C_{P1Y}) + (C_{P3Y} - C_{PHY}) = (R_{XX}\{X_3\} - R_{XX}\{X_1\})(Z_2 - Z_1)$$

Those equations describe the displacement effect along a diagonal, and allow calculating the X and Y rolls on a length of respectively P_1P_H and P_HP_3 . Even if they can be calculated, straightness defects L_{XY} and L_{YX} represent only local values, which take into account a part of the perpendicularity. For those reasons, the result is not accurate enough to be described.

3.4.2 Diagonals in the ZX plane

The compensation along a diagonal in the YZ plane is calculated from C_X :

$$C_X = L_{XX} + L_{YX} + L_{ZX} + R_{YY} \cdot (P_Z) - R_{YZ}T_Y + R_{XY} \cdot (P_Z) - R_{XZ}T_Y - R_{ZZ}T_Y$$

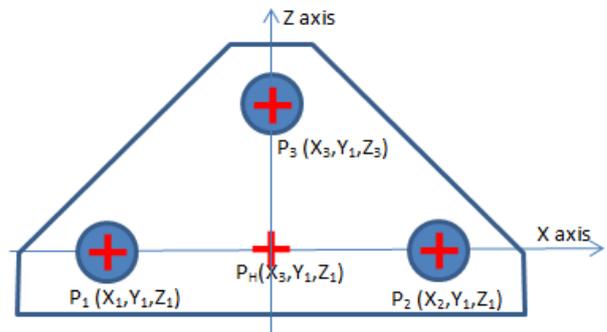


Figure 10: Diagonals in the ZX plane

The compensation on P_1P_3 in the ZX plane (fig. 10) can be written:

$$C_{P3X} - C_{P1X} = L_{XX}\{X_3\} - L_{XX}\{X_1\} + L_{ZX}\{Z_3\} - L_{ZX}\{Z_1\} - (R_{XZ}\{X_3\} - R_{XZ}\{X_1\})T_Y - (R_{ZZ}\{Z_3\} - R_{ZZ}\{Z_1\})T_Y + (R_{YY}\{Y_1\} + R_{XY}\{X_3\} - R_{XY}\{X_1\})(Z_3 - Z_1)$$

The linear effect on P_iP_H is:

$$C_{PXH} - C_{PX1} = L_{XX}\{X_3\} - L_{XX}\{X_1\} - (R_{XZ}\{X_3\} - R_{XZ}\{X_1\})T_Y$$

The difference between both equations gives:

$$(C_{PX3} - C_{PX1}) - (C_{PXH} - C_{PX1}) = L_{ZX}\{Z_3\} - L_{ZX}\{Z_1\} - (R_{ZZ}\{Z_3\} - R_{ZZ}\{Z_1\})T_Y + (R_{YY}\{Y_1\} + R_{XY}\{X_3\} - R_{XY}\{X_1\})(Z_3 - Z_1)$$

The same calculation in the second position in the ZX plane allows calculating the Z roll R_{ZZ} :

$$(C_{PX6} - C_{PX4}) - (C_{PXH2} - C_{PX4}) - (C_{PX3} - C_{PX1}) + (C_{PXH} - C_{PX1}) = (R_{ZZ}\{Z_3\} - R_{ZZ}\{Z_1\})(T_{Y1} - T_{Y2})$$

All the local straightness defects can be calculated with the same method, without any additional position.

3.4.3 Perpendicularity between axes

The calculation of perpendicularity between axes, two by two, is done from difference between the measured lengths of the triangle sides.

The product of the length of a side by the cosine of the real angle of perpendicularity should be equal to the same product on the other side (fig. 11).

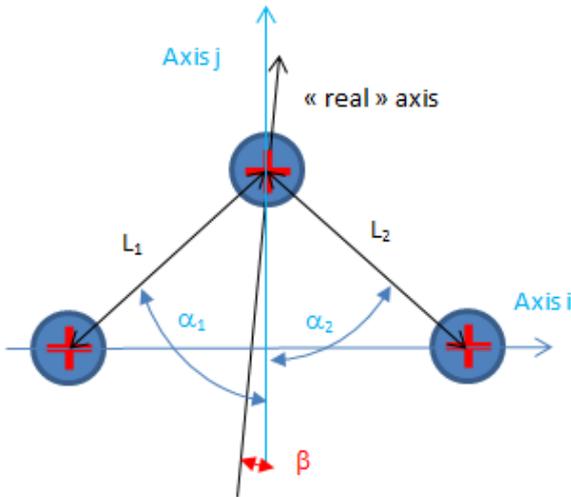


Figure 11: perpendicularity calculation

It can be written like this:

$$L_1 \cdot \cos(\alpha_1 - \beta) = L_2 \cdot \cos(\alpha_2 + \beta)$$

$$L_1 \cdot (\cos \alpha_1 \cos \beta + \sin \alpha_1 \sin \beta) = L_2 \cdot (\cos \alpha_2 \cos \beta - \sin \alpha_2 \sin \beta)$$

$$\cos \beta (L_1 \cos \alpha_1 - L_2 \cos \alpha_2) = -\sin \beta (L_1 \sin \alpha_1 + L_2 \sin \alpha_2)$$

So:

$$\tan \beta = \frac{L_2 \cos \alpha_2 - L_1 \cos \alpha_1}{L_1 \sin \alpha_1 + L_2 \sin \alpha_2}$$

β is the perpendicularity defect between two axes at a given position.

4. Real case example

As described previously, the standard can be measured horizontally or vertically (fig. 12). The global checking proposed here needs only 7 different positions.

The standard is considered as a perfect part (uncertainties known), so the defects are affected to the CMM geometry.

The measured lengths and angles are exported in a spreadsheet, and compared to the theoretical values. It's also useful to export tip offsets, and diameter of each measured circle. The length deviations are assimilated to residual compensation defects, so that each parameter can be calculated with previous equations (chapter. 3).

The total measurement (7 positions, 3 repetitions) takes less than 1 hour, instead of 2 hours for ISO10-360-2 test, or 1 hour for ball bar test, which don't point out the bad parameters. Automation allows treating results directly, so that the bad parameter(s) can be corrected quickly. A partial control, which gives only a picture of linear defects and perpendicularities, can be done in few minutes. It allows checking parameters that are most sensitives.

A tolerance has to be defined for each parameter to point out any abnormal deviation. This tolerance should depend on the CMM type, the probe, the stylus...

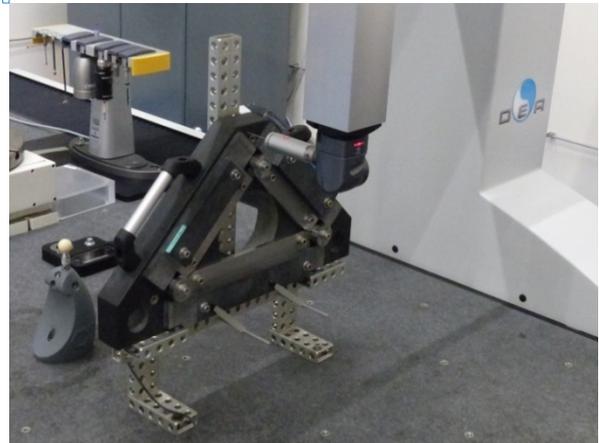


Figure 12: standard vertically positioned (ZX plane)

Usually, the length deviation average (3 lengths, 7 positions, 3 repetitions) should be close to zero, the standard deviation close to standard uncertainty.

Conclusion

This new standard allows a fast checking of the global CMM geometry, with results linked to metrological definition of the meter. Furthermore, in case of defects, the standard permits defining the bad parameters.

All the measurements give also information about uncertainty on lengths and angles on the CMM.

The assembly is easy to do, and the uncertainty caused by it is negligible, if it's done properly. This study had been done with a prototype. Other sizes or forms are

described in the patent, and allows optimizing the checking for different CMMs.

Using this new tool is a good way to perform an effective traceability of a CMM geometrical quality.

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