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Object Based Temperature Compensation for "Shop floor" CMM

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ABSTRACT

With the current closed loop manufacturing trend, the Coordinate Measuring Machine (CMM) is finding a new role as a flexible production gauge located directly behind the machine tool or production process. In high technology productions, there are necessary of inspection of many form and position dimensions. There are specifics of working with "Shop floor" CMM and one of the main problems is temperature deviation which affect the geometric parameters of controlled objects. To improve the performance of the "Shop Floor" CMM we introduce two types of "Object based" temperature compensation based on a specific object with a database created for, at different ambient temperature values in a wide range.

KEYWORDS

Coordinate Measuring Machine, Shop floor CMM, temperature compensation

INTRODUCTION

Geometric measurement is the foundation of modern metrology, being the earliest and largest important branch in the field of measurement and also the foundation for the development of modern science and technology. At present, geometric measurement in various fields has developed different types of measurement techniques or instruments and has presented a trend of mutual integration; coordinate measurement technology is undoubtedly among the best.[1,10]. Coordinate measurement technology is the most common and fundamental measurement technology in the field of modern machinery manufacturing, especially in aerospace, automobile manufacturing, mold processing, and other industries. At present, the whole life cycle of the product development, design, processing, measurement, acceptance, use, maintenance, scrapping and so on must follow the GPS standard system in the field of manufacturing. [5,9].

The development trends in high-tech industries give a central place to Shop Floor CMM, which allows quality control close to the machine tool directly in the production, monitoring and adjusting process. In particular when you are measuring close to production activities, it is important to ensure that fluctuations in the ambient temperature do not affect the accuracy of your measurements. [12]. Current geometric tolerance become lower and lower, so industry need more accurate gauges. In high technology productions as automotive and aircraft industry, there are necessary of inspection of many position and form dimensions and many combination of different materials These requirements make the Shop floor CMM of critical unit in for the production process.

During CMM measurement, all relevant factors may have an impact on the measurement results. The sources of uncertainty in the coordinate measuring system can be divided into five categories according to the analysis method of "personnel, machine, object, method and environment" commonly used in product quality management. Uncertainty caused by CMM instrument's own errors, measured workpiece, surveyors, measuring method, and external environment.[10]. Based on the requirements of the market (consumers) and the development trends, ambient temperature can have the most impact on a CMM's accuracy and repeatability. Changes in temperature can affect the scales, machine structure and artifacts being measured to expand, contract, and, in some cases, distort in a non-linear manner.

The manufacturer shall state a hypothetical maximum permissible error of the CMM (MPE) of the size measurement indication, MPEE, according to industry standard ISO 10360-2 in the temperature range 18÷22°C as [3]:

$$MPEE = \alpha + \frac{\beta * L}{1000} \quad (1)$$

Where MPEE is in microns, and L is the measurement length in millimeters, α - coefficient define by manufacturer for MPEE, β - coefficient determining the component of the error based on the measured length L[3].

Typically, CMM manufacturers specifying accuracy by way of multiple temperature bands as:

$$MPEE = \alpha_i + \frac{\beta_i * L}{1000}\{\tau_i\} \quad (2)$$

Where MPEE is in microns, and L is the measurement length in millimeters, α - coefficient define by manufacturer for MPEE, β - coefficient determining the component of the error based on the measured length L, i - temperature band number, τ - temperature band.

For "Shop floor" CMM, MPEE could be illustrated as:

$$MPEE = \alpha + A * \Delta T + \frac{(\beta + B * \Delta T) * L}{1000}\{T_1 \div T_2 °C\} \quad (3)$$

Where MPEE is in microns, and L is the measurement length in millimeters, α - coefficient define by manufacturer for MPEE, β - coefficient determining the component of the error based on the measured length L, i - temperature band number, τ - temperature band, A,B - coefficients taking into account the change of the MPEE as a function of ambient temperature variation.

OBJECT BASED" TEMPERATURE COMPENSATION

As a standard in CMM, software temperature compensation is used to reduce the influence of temperature change on the structure and there is a possibility for linear temperature compensation of the objects from different materials.

Unfortunately, this does not allow temperature compensation of objects that are a combination of two materials with a large difference in coefficients of thermal expansion (aluminum and Carbon fiber, various plastic polymers or stainless steel).

Another specific problem is the non-linear temperature deformations in parts with a complex configuration, which affects the parameters of form and location.[6]

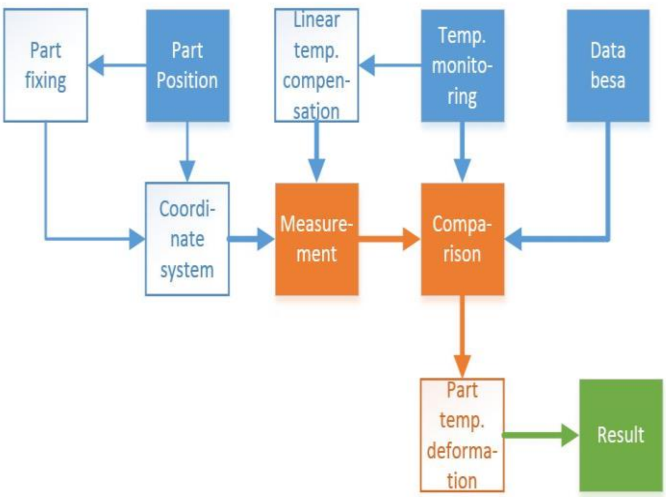

Figure 1: Block diagram for application of "Object based" temperature compensation.

To improve the performance of the “Shop Floor” CMM, “Object based” temperature compensation can be used based on a comparison of the measurement results of a specific object with a database created for it at different ambient temperature values in a wide range. (Figure 1)

There are two different ways for introducing "Object based" temperature compensation - based on CAD compare and based on "point by point" compare.

First method based on CAD compare use a database with different CAD models of the part, measured at different ambient temperatures and stored in data base. This method allows measurement by scanning an unlimited number of points. Main advantage is related to possibility of control of profile and surface, which is tendency in automotive industry. A disadvantage can be pointed out changing the temperature during the measurement process. This disadvantage can be compensated by the second method - "point by point" compare. We use a limited number of points, introducing compensation for each point, for each change in temperature - "temperature variation map".

A key point for the realization of the "Object based" temperature compensation is the unambiguous basing and definition of a coordinate system independent of the temperature deformations and possible for recalculation with a temperature coefficient for linear expansion of the materials (calculated or empirically established).

TEMPERATURE COMPENSATION BASED ON CAD COMPARE

A geometrical feature is a generalized term, which, depending on the relevant conditions, can be a point line or a surface. The following types of geometric features are considered in EN ISO 17450-1:2011.[4] According to the standard, the deviation of the form is defined as the maximum distance from the points of the extracted feature to the associated feature along the normal to them.[4] When using the RMS (root-mean-squares) associated feature, the deviation of the form is defined as the sum of the absolute values of the distances from the two extreme points of the extracted feature located above and below the associated feature normal to them (Fig. 2).

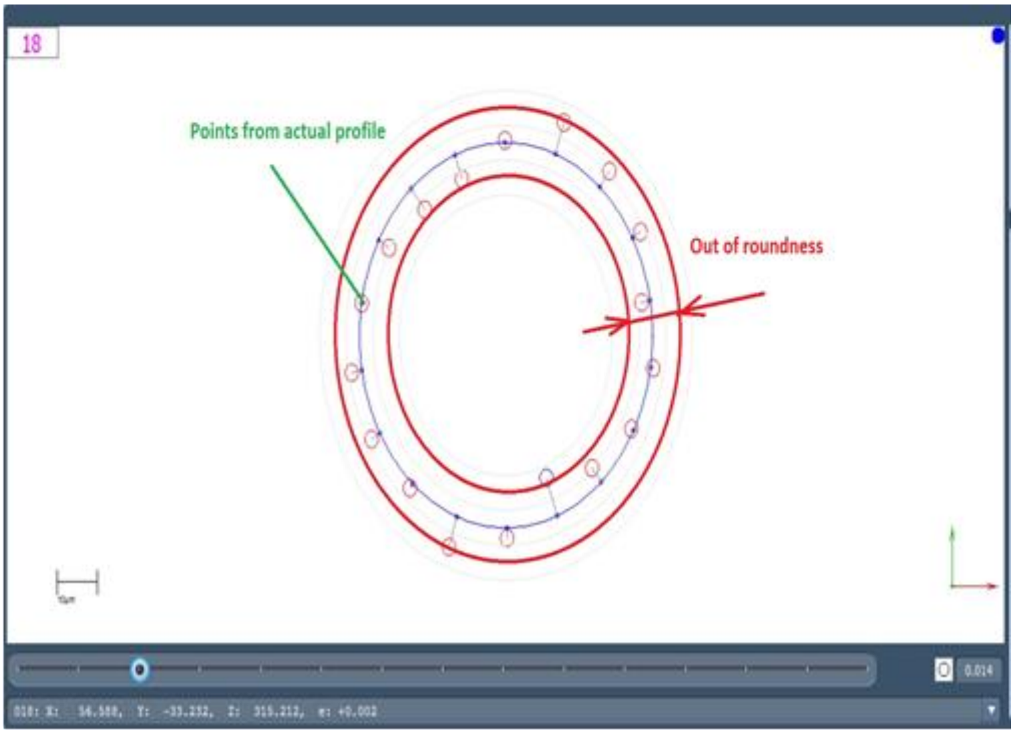

Figure 2: Feature measurement with Aberlink 3D v4 software

As an example for realization of CAD compare based Temperature compensation we could present the roundness deviation. Roundness is defined as a condition of surface of revolution where all points of the surface intersected by any plane perpendicular to a common axis are equidistant from the axis. This leads to the definition of out of roundness as a measure of roundness error of a part. Roundness error is the radial distance between the minimum circumscribing circle and the maximum inscribing circle, which contain the profile of the surface at a section perpendicular to the axis of rotation (Fig. 2).[7]

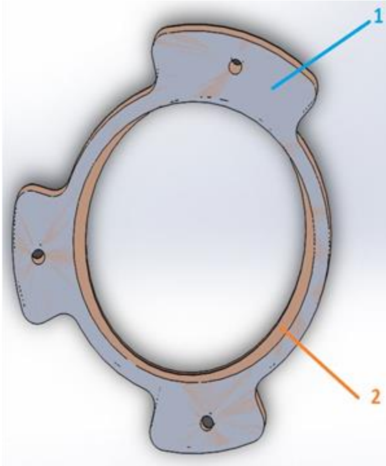

Figure 3: CAD Model of flange mesured on differen temperature: 1. Measured 20°C; 2. Measured 30°C

The main point in the realization of the temperature compensation based on CAD compare is the use of the extracted integral feature at temperature t_i (temperature at the moment of measurement) as a basis for creating a CAD model for data base. Then use this model as an output element for comparison with measured at the same temperature object. CAD models data base can be created after simulation of temperature variation by special software (Fig. 3.). Regardless of which method we use, the resulting CAD Model has an irregular shape, but we use it as a starting point for determining the deviation from the shape. The same is with true position. Before applying of the temperature compensation based on CAD compare there are temperature deformation which affects on form of measured feature at $T_i \neq T_0$ (ambient temperature different from 20°C) as shown on Fig. 2.

We could use a CAD model with deformation at T_i as a starting point for comparison (Fig. 4.). As a result we get a feature which deviation of form is calculated from deviation of measured profile compared to CAD model. Main point of realization of temperature compensation based on CAD compare is aligning the part to CAD model. At first we measure and define referent elements (features) which is being used for linking. Then we calculate RMS error (Root Mean Squared representing the mean errors of all the points) to see how much model corresponds to real part. This error is unavoidable when measuring deviation from profile and surface by comparison with CAD Model[11]

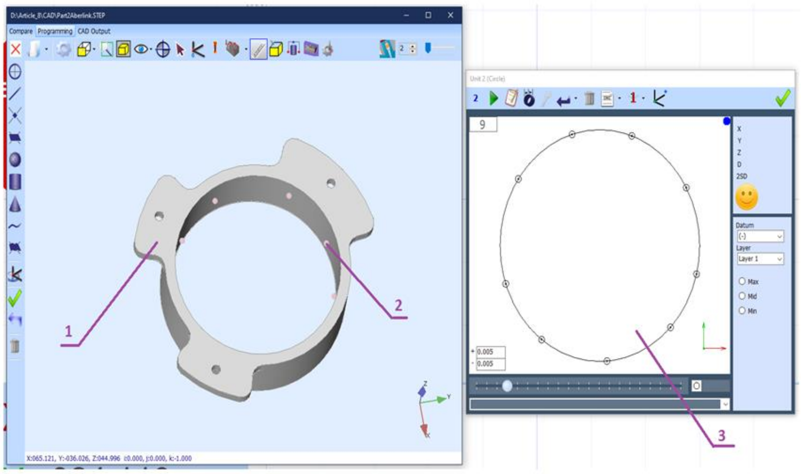

Figure 4: CAD Compare / CAD Programing with Aberlink 3D v4 software: 1. CAD model; 2. Measured points; 3. Measured feature[11]

"POINT BY POINT" TEMPERATURE COMPENSATION

For the realization of the "Point by Point" temperature compensation method we use nominal point position $A_{0i}(x_{0i},y_{0i},z_{0i})$ points from the extracted element point position A_{ti} (x_{ti},y_{ti},z_{ti}) at temperature t_i (temperature at the moment of measurement), which we store in a "temperature variation map".(Fig. 5)

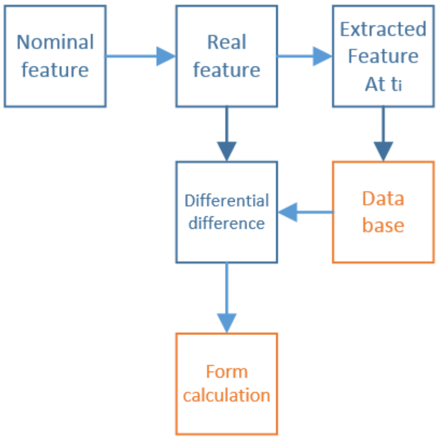

Figure 5: Block diagram for application of "Point by Point" temperature compensation

For the realization of the "Point by Point" temperature compensation method it is necessary to provide unambiguous positioning of the measured part (by fixation regardless of the temperature deformations) or unambiguous determination of the datum features defining the coordinate system of the part.[8] This allows us to identified the radius vectors (ji(in X direction), ki(in Y direction) and mi(in Z direction)) of the compensation direction when compared to the data stored in a "temperature variation map". So we need a finite number of points, with variations in their coordinates at different temperatures (t_i) or in different temperature ranges (Δt_i), in conjunction with their radius vectors, to calculate the differential change in the deviation from the shape or position of the controlled features.

Table 1: Temperature error map variation “with coordinates of points and radius vectors for different temperatures

Temperature	A			B			…	L			…
t=20°C	xA	yA	zA	xB	yB	zB	…	xP	yP	zP	…
	PA			PB			…	PL			…
	jA	kA	mA	jB	kB	mB	…	jP	kP	mP	…
t=21°C		A’			B’		…		P’		…
	xA’	yA’	zA’	xB’	yB’	zB’	…	xP’	yP	zP’	…
	PA			PB			…	PL			…
	jA	kA	mA	jB’	kB’	mB’	…	jP’	kP’	mP’	…
ti=(20+n.i)°C	Ai			Bi			…	Pi			…
	xAi	yAi	zAi	xBi	yBi	zBi	…	xPi	yPi	zPi	…
	PA			PB			…	PL			…
	jA	kA	mAi	jB	kB	mB	…	jP	kP	mP	..

Shape deviation is calculated as the maximum distance from the differential difference between the nominal position of point A (xA, yA, zA) and the extracted position of the point at temperature ti - Ai (xAi, yAi, zAi), that is, the deviation of the shape of the element is ΔAi (Δxi, Δyi, Δzi) at the same radius vectors pA(jA,kA,mA)= pA’(jA’,kA’,mA’)= pAi (jAi,kAi,mAi)= pA(jA,kA,mA) (Фиг. 9.):

$$\Delta A\ (\Delta xi, \Delta yi, \Delta zi) = \Delta A\ (xA - xAi),(yA - yAi),(zA - zAi) \quad (4)$$

When using the RMS-related function, the shape deviation is defined as the sum of the absolute values of the distances from the two endpoints of the differential difference between the nominal position of the point and the position of the point of the extracted element at temperature ti - ΔAi (Δxi, Δyi, Δzi) located above and below the element located normally to them. The point-to-point temperature compensation method gives us an easy way to calculate the profile deviation (ECL) or surface (ECE)[1], due to the point-to-point comparison between the measured coordinates and the coordinates stored in the temperature variation map.

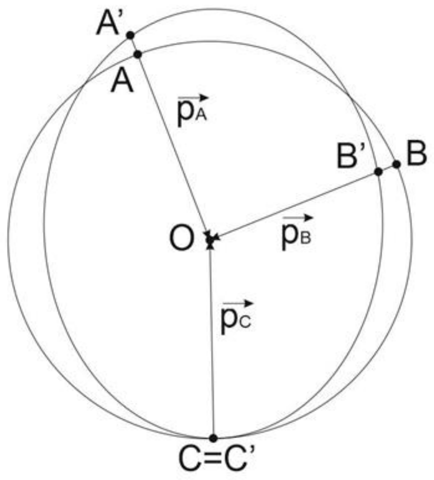

Figure 6: The deviation of the form realized by the method "Point-by-point" and use „temperature error map variation"

CONCLUSION

The development of measuring equipment and in particular of coordinate measuring machines allows reducing the effect of ambient environmental impact over the measurements. Improvements in the characteristics of "Shop floor" CMM can be achieved by "object based" temperature compensation, which allows to reduce the influence of temperature deformations in determining deviations of form and location of features in details, a combination of different materials at wide range of changes in ambient temperature.

REFERENCES

[1] N. Cappetti, A. Naddeo, F. Villecco, "Fuzzy approach to measures correction on coordinate measuring machines: The case of hole-diameter verification", Measurement, Vol. 93, Pp. 41–47, 2016.

[2] ISO 1101, "Geometrical Product Specifications (GPS)", Geometrical Tolerancing—Tolerances of Form, Orientation, Location and Run-Out, 2017.

[3] ISO 10360-2, "Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM)", — Part 2: CMMs used for measuring linear dimensions, 2009.

[4] ISO 17450-1. "Geometrical product specifications (GPS)", General concepts - Part 1: Model for geometrical specification and verification, 2011.

[5] R.J. Li, K.C. Fan, Q.X. Huang, H. Zhou, E.M. Gong, and M. Xiang, "A long-stroke 3D contact scanning probe for micro/nano coordinate measuring machine", Precis. Eng., 2016, 43, 220–229, 2016.

[6] N.V. Raghavendra, I. Krishnamurthy, "Engineering metrology and measurements", Oxford University Press 2013, ISBN-13: 978-0-19-808549-2

[7] H.R. Radev, "Metrologiya i izmervatelna tehnika", vol. II, S., Softtreyd, 2010, ISBN: 978-954-334-093-4.

[8] J.A. Stadek, Coordinate Metrology, Springer 2020, ISBN 978-3-662-48465-4

[9] R. Thalmann, F. Meli, A. Küng, "State of the art of tactile micro coordinate metrology", Appl. Sci., Vol. 6, Pp. 150, 2016.

[10] C. Yinbao, W. Zhongyu, C. Xiaohuai, Y. Li, H. Li, H. Li, W. Hanbin, "Evaluation and Optimization of Task-oriented Machines Based on Geometrical Product Specifications", Appl. Sci., Vol. 9, Pp. 6, 2019. www.mdpi.com/journal/applsci, ISSN: 2076-3417

[11] https://www.aberlink.com/

[12] https://www.metrology.news/