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Analysis of “Shop floor” CMM and options for improvement of characteristics with "Object based" temperature compensation

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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. Current geometric tolerance become lower and lower, so industry need more accurate gauges. In high technology productions, there are necessary of inspection of many form and position dimensions. There are specifics of working with "Shop floor" CMM, determining the differences with conventional CMM working in a laboratory environment. These specifics are mostly related to the environment and its impact on the object of measurement. 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 part with a database created for it at different ambient temperature values in a wide range.

Keywords – Coordinate Measuring Machine, Shop floor CMM, temperature compensation

I. INTRODUCTION

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. Shop floor CMM has been improved in an attempt to create a thermally inert device. The developed volumetric error compensation techniques has significantly enhanced the accuracy. In addition thermal compensation techniques are common place to overcome temperature issues associated with shop-floor measurements. Closed loop feedback with CNC machine-tool offset information can be interpreted real-time allowing offset values to be updated to the CNC controller, enabling true automated process control compensating for common causes of process instability such as example tool wear and thermal drift. [7]

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. These requirements make the Shop floor CMM of critical unit in for the production process.

II. BENCHMARKING

As initial data for the analysis and evaluation of the metrological and operational characteristics of “Shop floor” CMM, we consider the main characteristics of such systems offered by the leading manufacturers. (Table 1). [5, 6, 8, 10]

For the realization of different types of CMM manufacturers also use different schemes: non-Cartesian parallel kinematic, Delta mechanism, Horizontal arm, Moving bridge and Gantry. Another important design feature is related to the type of guides - Air bearings or Air free bearings. Despite these features, the main goal of the manufacturers is to maintain the metrological characteristics in a wide temperature range compared to conventional CMM.

Table -1 TABLE I. BENCHMARK OF CHARACTERISTICS OF "SHOP FLOOR" CMM [5, 6, 8, 10]

Manufacturer	Aberlink	Aberlink	Mitutoyo	Hexagon	Leitz	Zeiss
Model	Xtream	Extol	MiSTAR 555	7.10.7 SF	SIRIO SX	CenterMax
Construction type	non-Caresian parallel kinematic	Delta mechanism	Horizontal arm	Moving bridge	Horizontal arm with rotary table	Gantry
Range (mm)	Dia. 510, Z 270	Dia. 520, Z 300	570x500x500	710x1010x680	600x800x900	1100x1200x900
Accuracy (um)	3+0.4L/100	2.6+0.4L/100	2.2+3L/1000	3.5+3L/1000	1.5+L/400	1.2+L/280
Temp. range (°C)	0 to 45	0 to 45	10 to 40	15 to 40	18 to 40	15 to 40
Bearings	Linear motors and mechanical bearings (Air-Free)	Fully sealed recirculating bearings	Linear Guideways for Air-Free	Air bearings with dust protection	Air bearings with dust protection IP54	Air bearings with dust protection IP54

Based on the requirements of the market (consumers) and the development trends, some of the main characteristics influencing the accuracy of the "Shop floor" CMM related to the specific of working with them can be considered. (Fig. 1)

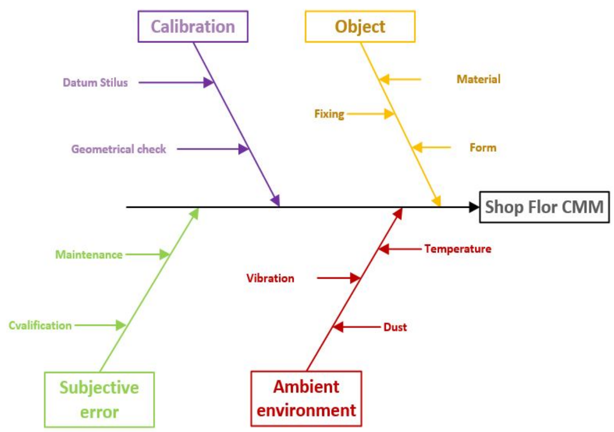

Figure 1. Characteristics influencing the accuracy of the "Shop floor" CMM

There are specifics of working with "Shop floor" CMM, determining the differences with conventional CMM working in a laboratory environment. These specifics are mostly related to the environment and its impact on the object of measurement. It is therefore appropriate to focus efforts on improving accuracy depends on these characteristics. The significance of these characteristics can be illustrated by the use of Pareto analysis. (Fig. 2)

Manufacturers are taking various actions to reduce the influence of the environment on the characteristics of the "Shop Floor" CMM. Light-weight Bellows and Covers allow machine components to be protected while minimizing friction for smooth-running and precise performance. To improve the temperature characteristics are used thermal isolation elements, as well as temperature compensation, ensure accuracy is maintained in changing shop-floor temperatures. Some producer use artificially aged special concrete mix with a through-flow liquid ventilation system increases the thermal conductivity. To reduce vibration are used the standard elastomeric materials or active vibration isolation system. [6]

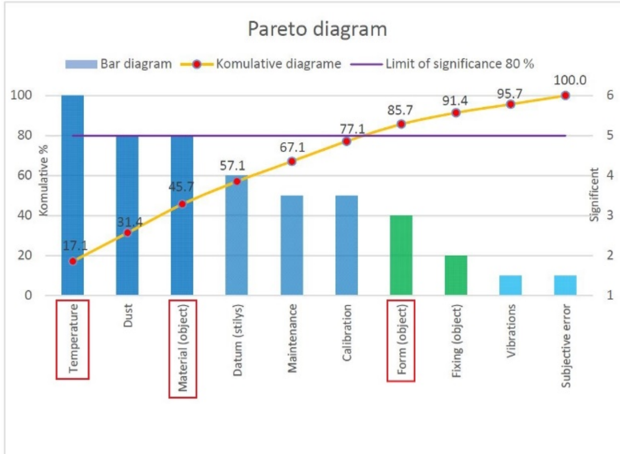

Figure 2. Characteristics influencing the accuracy of the "Shop floor" CMM

We focus our efforts on improving the characteristics of the "Shop floor" CMM related to the ambient temperature variation, the material of the part and the compensation of the nonlinear change of shape as a function of temperature.

III. TEMPERATURE COMPENSATION.

Compared to other environmental factors found in a factory, 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. [4, 9]

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:

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

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.

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

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

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:

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

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.

IV. "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.

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. (Fig. 3)

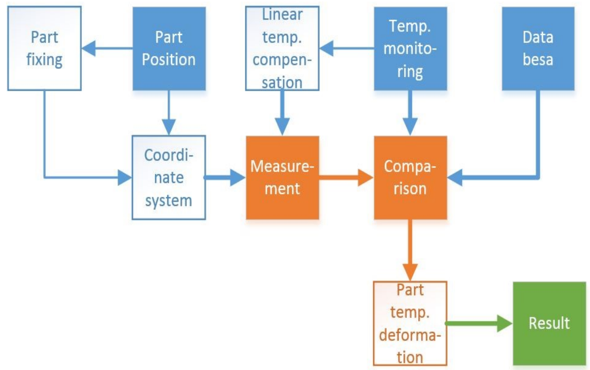

Figure 3. Block diagram for application of "Object based" temperature compensation.

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, but has the disadvantage of 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).

A. 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 (Fig. 4).[1]

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.[3]

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.[3]

The main point in the realization of the temperature compensation based on CAD compare is the use of the extracted integral feature at temperature ti (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.

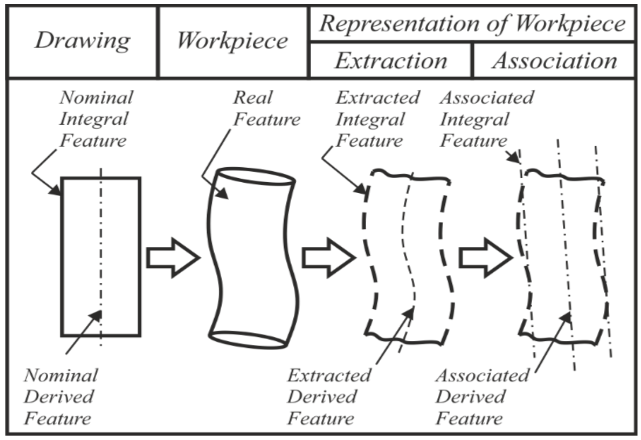

Figure 4. Various feature types

The main difference from the standard is that we calculate the deviation of the form as the maximum distance from the points of the CAD model to the associated feature along the normal to them.

When using the RMS 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 CAD model located above and below the associated feature normal to them.

B. "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)

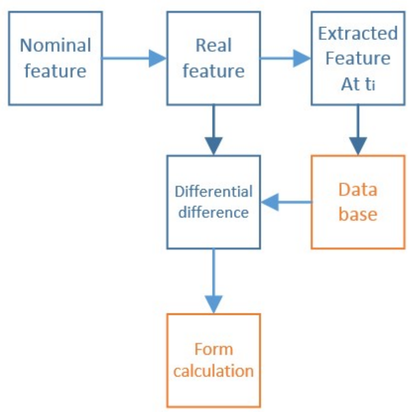

Figure 5. Block diagram for application of "Point by Point" temperature compensation

The deviation of the form is calculated as the maximum distance from the differential difference between nominal point position and extracted element point position - ΔA_i $(\Delta x_i,\Delta y_i,\Delta z_i)$, to the associated feature along the normal to them.

When using the RMS 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 differential difference between nominal point position and extracted element point position - ΔA_i $(\Delta x_i,\Delta y_i,\Delta z_i)$ located above and below the associated feature normal to them.

"Point by Point" temperature compensation method give us easy way for calculation of deviation of the profile (ECL) or surface (ECE), because of is point by point compare between measured coordinates and coordinates stored in temperature variation map.

IV.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.

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