CALIBRATION OF CMM BY 3-DIMENSIONAL COORDINATE COMPARISON

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1 INTRODUCTION

This paper presents a new calibration method particularly for up to middle size CMM. The method is able to provide the 21 parametric errors only by performing the coordinate comparison. An automated calibration system for production stage of CMM is realized.

Numerical compensation of geometry for CMM has been popular in these days. Still, each specific mechanical component may show peculiar shape in its geometry due to manufacturing reasons. This fact requires manufacturers to calibrate and map the naked geometric error of CMM on the production stage each respectively.

Several methods have been proposed [4]. Direct assessment of the error component by adequate instruments e.g. laser interferometer or electric level are adopted. This method has been widely used since each error component can be detected directly with reasonably high accuracy and high spatial density instead its tedious operation complexity. Other trend in the recent years is introduction of the artefact method typically performed on the ball plate [1]. Reasons the method become popular can be: 1) tools with inexpensive and ease to use realizes rapid calibration, 2) well known mathematical processes are able to distribute indication error obtained by the artefact measurement into the parametric errors of CMM, e.g.[2][3].

Paying attention to robustness and automation possibility of the artefact method, authors consider building a new calibration method which utilizes a kind of programmable three dimensional sphere grid maintained by the reference CMM. The object CMM can then be calibrated by means of three dimensional coordinate comparison. Handing over portability, such as possibility of onsite calibration at customer site, to already proposed artefact method, the study is to be focused on the parametric calibration of up to middle size CMM in the production floor.

2 COORDINATE COMPARISON

Figure 1 shows a schematic of the proposed calibration system. The reference CMM attaching a touch trigger probe and a sphere on its measurement spindle traverses and positions successively to form a virtual sphere grid. The calibration of an object CMM is carried on by performing three dimensional coordinate comparison through the sphere feature as shown on Fig. 2. The system superimposes the measurement volume of the reference CMM into that of the object CMM. While the appearance bears some resemblance to that of the calibration with the ball cube, the method introduces characteristic which is able to obtain higher data density in space as the conventional direct method.

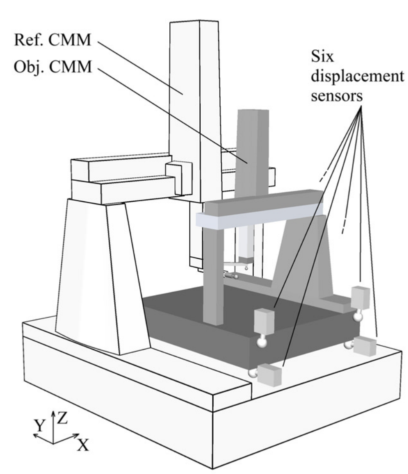


Fig. 1 Schematic of three dimensional coordinate comparison

2.1 Relative sphere position

Relative position information of sphere is essential to quantify indication error of the object CMM in the measuring volume since observed indication error is input to the whole calibration procedure. The parametric error of the CMM is acquired as the final calibration result. The parametric error obtained only by using the relative position information may provide Cartesian coordinate frame to the object CMM. It is necessary to consider way to keep traceability to the length standard.

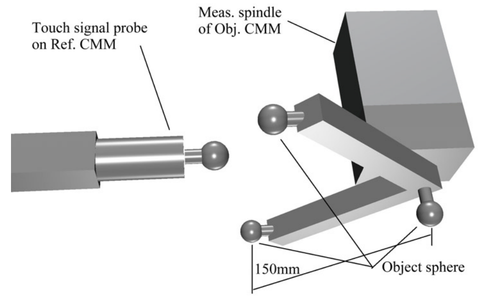


Fig. 2 Example of three probe vectors on object CMM

2.2 Traceability to Length Standard

Geometric calibration activity generally demands a standard gauge with smaller uncertainty, typically one fifth or one third, than that of the object to be calibrated. It seems however economically not to be wise to require small enough uncertainty for every measurement task on the reference CMM for the three dimensional coordinate comparison. Based on fact that it is not difficult to maintain reasonably accurate Cartesian coordinate frame on the reference CMM the traceability of the calibration system to the length standard can be kept by adopting an end gauge. The other possibility is to describe statistically propagated uncertainty through linear system [6].

2.3 Calculation of Parametric error

There are two major methods to calculate parametric errors of CMM. One is *step by step calculation* and the other is *linear regression*. The former evaluates each parametric error by corresponding measurement. The latter estimates parametric errors at once from a batch of observation data. Referenced reports[1,4] indirectly compare some aspects of these two methods as *direct method* and *self calibration method*. With all their differences, [4] reports that there is no significant different result observed. Authors take a similar view about result of the calibration of CMM. It seems safe to say that either calculation principle provides comparable result.

However, actual measurement procedure required by the adopted calculation principle shows different view. Adopting *step by step calculation* a set of the measured points have direct relation with the corresponding parametric error. It means that measurement strategy drawing spatial distribution of observation points is fixed depending on the kinematic structure of the CMM. On the other hand, adoption of *linear regression* allows us to arrange positions for measurement almost arbitrary if proper response is kept for the focused parametric error. A kind of programmable sphere grid is going to be built. Noticing the flexibility, the latter method is chosen here to calculate the parametric error.

Adopted model includes 21 parametric error components and typical components for thermal expansion. Major components are described by piecewise polynomials with proper order respectively. The model is so designed as to be solved by conservative linear regression technique. Estimated components can be transferred to a CMM controller to execute error compensation.

3 CALIBRATION EXPERIMENT

The calibration method and the measurement strategy mentioned in the above are applied on CMM in the production floor. Here, one of the typical example is presented.

3.1 Measurement strategy

Observation of the indication error of the object CMM carries on like that of the ball plate method as follows. The reference CMM traverses and positions a sphere supported on the measurement spindle. The object CMM measures this sphere by co-operating with a touch signal probe and the other sphere on it. Simple least squares give the center coordinate of the sphere as the indication error of the object CMM. Fixing the approaching procedure to measure the sphere, major systematic errors caused by the touch signal probe can be rejected from the calibration result.

An example of the designed measurement strategy is shown in Fig. 3. Approximately 400 points are positioned and measured to accumulate indication error of the object CMM. Calibration measurement on CMM requires us to adopt at least three different probe vector if all 21 parametric errors are to be evaluated. The requirement is also fulfilled on the measurement strategy shown in Fig.3 although it is not visible.

3.2 Observed indication error

Figure 4 shows an example of indication error of the object CMM. The data is obtained on the measurement line along the *X* axis. A couple of figures a) on the left side is measured at *Z*=400mm that is the top of the volume. The b) on the right side is at *Z*=0mm the bottom of the volume. Each plot from the top to the bottom corresponds to deviation in *X*, *Y* and *Z* direction respectively. The circle and the square indicates measurement direction in forward and reverse. It is clear that three dimensional indication error of the object CMM is measured with high spatial density under the fully automated operation.

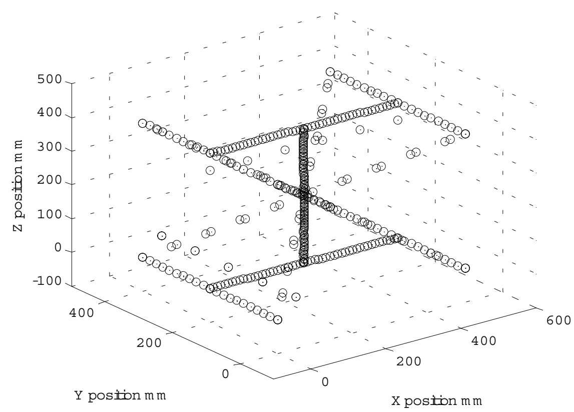
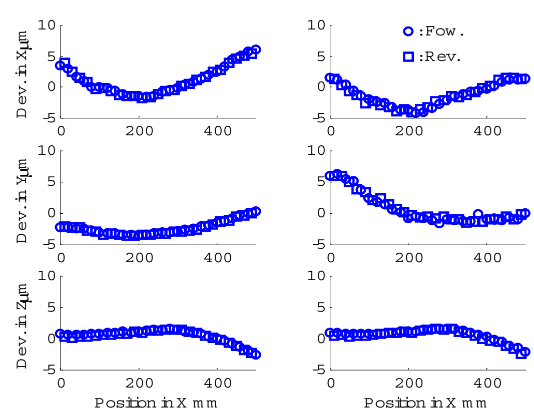


Fig. 3 Measurement strategy for coordinate comparison

3.3 Measured and Predicted Error

Figure 5 shows the indication error of the object CMM actually measured by the three dimensional coordinate comparison and the predicted error calculated from the estimated parametric errors. The estimated parametric error can be used to compensate the CMM. When the model explains geometrical error of the object CMM perfectly the measured error and the predicted error become a pair of vectors with equal length in opposite direction. Figure 6 shows the estimation residual by subtracting them. As far as visually observing distribution of residual error there seems not to be systematic trend.



a) *Z*=400mm b) *Z*=0mm

Fig. 4 Observed three dimensional deviation along *X* axis of object CMM

3.4 Verification by Conventional Calibration

Since it seems not simple to compare the whole consequence from the three dimensional coordinate comparison method and that from the conventional calibration method. Adopting both calibration method on a CMM, spatial distribution of the estimated parametric errors are compared to see some aspects of the verification. Figure 7 presents a comparison example of one of the *X*

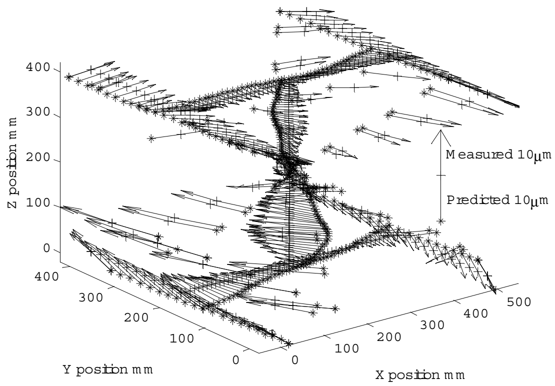


Fig. 5 Measured and predicted deviation

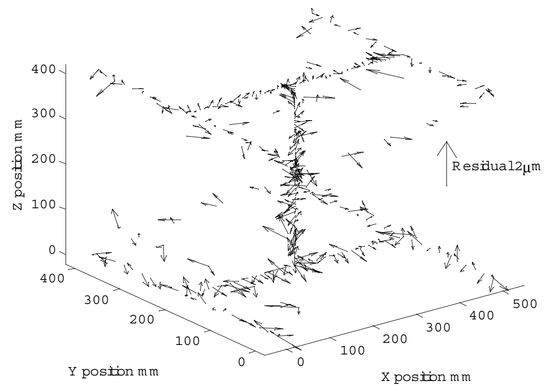


Fig. 6 Estimation residual after calibration

straightness component. With in the top plot, the solid line shows the component obtained by the three dimensional comparison method. The broken one does the component obtained by the conventional laser interferometer respectively. The bottom plot shows difference of the two components in the top plot. Both components agree with each other well.

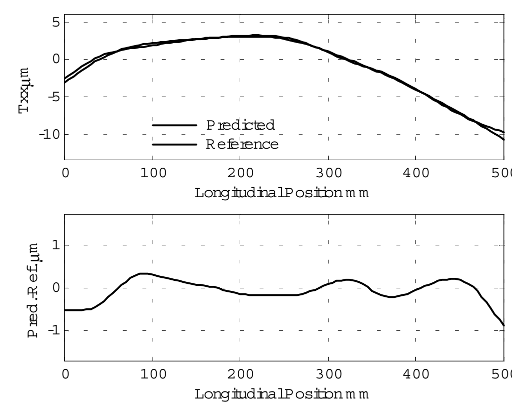


Fig. 7 Example of component comparison, *X* axis straightness in *Z* direction

4 SUMMARY

A new calibration method for CMM is proposed. A fully automated calibration system for up to a middle size CMM is realized by direct coordinate comparison between two CMMs. The system does not require any human operation after its starting till the end. The method may contribute to improve productivity of CMM in the production floor. The parametric error obtained by the three dimensional comparison method shows satisfactory coincidence with that obtained by the conventional direct measurement. Sufficient reliability of the calibration performance is confirmed.

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