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GEOMETRIC CALIBRATION OF CMMs USING 3D LENGTH MEASUREMENTS

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Abstract: This paper presents a new calibration method for larger size co-ordinate measuring machines (CMMs). This method provides 21 parametric errors by performing 1-dimensional length measurements in the workspace of a CMM. A special measurement set up is realised, which enables automated volumetric error compensation of CMMs at their production stage. Located in a corner of the measuring volume, this laser set up performs multiple spatial linear interferometer measurements by movement of a CMM automatically. In this paper emphasis is placed on; i) automation of spatial laser interferometer measurements, ii) minimising cosine errors by optimisation of the interferometer signal, iii) measurement strategy and iv) verification of the calibration.

Keywords: Co-ordinate measuring machine, volumetric calibration, parametric errors, interferometer

1 INTRODUCTION

Supposing that probe errors are left out of consideration, imperfect movement of carriages along the guides and deviations in the linear encoders primarily determine the accuracy of co-ordinate measuring machines. The kinematic structure of a CMM links these so-called parametric errors to deviations in the position of the probe tip. Figure 1 represents the geometrical structure of a moving bridge CMM, including its 21 parametric errors. The first character of each error denotes the axis of movement, according to the VDI/VDE 2617 guideline [1].

Assessment of larger size CMMs can be performed by artefact-measurements [2] or commercially available laser interferometer systems. In both cases a technician performs an optimised set of measurements, chosen in conformance with the kinematic structure of the CMM. These methods are expensive, time-consuming and require skilled personal.

An automated calibration system for middle size CMMs was presented earlier [3]. However this technique is not suited for larger size CMMs.

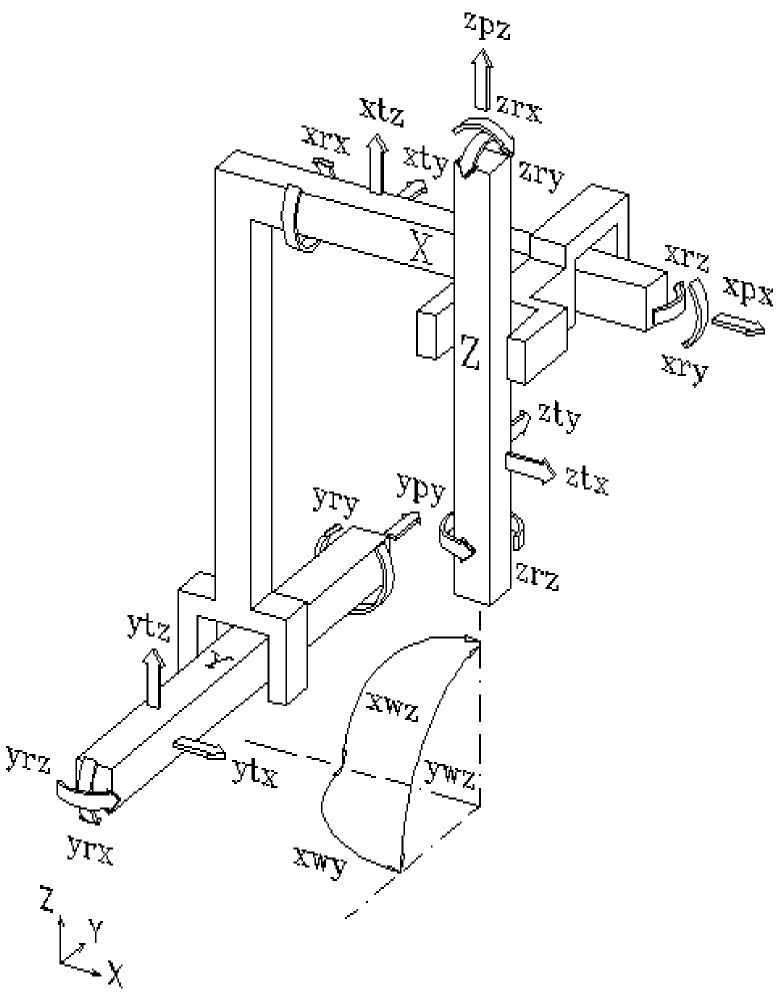

Figure 1. Parametric errors of a three-axis CMM.

Therefore a complementary calibration method is developed, which uses the so-called brute force method [4]. Many lengths in many different locations, distributed throughout the complete workspace of the CMM, are measured automatically.

2 AUTOMATED MEASUREMENTS

A laser interferometer is used to acquire data about the performance of a CMM. At least two methods are presented to automate laser interferometer measurements, namely tracking [5] and auto-alignment systems, e.g. [6][7]. In both cases photodetectors control the orientation(s) respectively position of the interferometer(s), however the determination of the end-effector's position is different. The first method uses the trilateration technique; multiple interferometer systems track the movement of the machine simultaneously. In contrary to the second case where only one interferometer system compares the moved distance of the CMM with the observed length of the laser.

Authors present here, an alternative method to fully calibrate larger size moving bridge CMMs. The proposed technique is comparable to the auto-alignment method, however the presented system aligns the CMM in accordance with the orientation of the laser beam instead of the other way around. Furthermore all parametric errors are determined by performing only 1-dimensional length measurements in its 3-dimensional workspace.

2.1 Principle of measurement

The presented method uses a laser interferometer in combination with a tuneable mirror surface (see figure 2). This so-called PH9-Mirror varies the orientation of the laser beam, by the ability to rotate around two axes. It reflects the laser beam into the measuring volume of a CMM and a so-called PH9-Retroreflector, which consists of two retroreflectors, reflects it back towards a receiver. By moving one of the retroreflectors exactly along the laser beam, the length measuring capabilities of the CMM are evaluated.

To enable automatic control, the mirror and retroreflectors are attached to Renishaw motorised probe heads. Changing their settings enables measurements at different locations in the workspace of a CMM. If the mirror is located in a corner of the measuring volume, a maximum of approximately 80 automated spatial laser interferometer measurements is possible.

By using two retroreflectors it is possible to do similar measurements with different probe vectors, making it possible to determine 21 parametric errors. This so-called probe vector defines the distance between the CMM's probe adapter and retroreflector and its choice is dependent on the direction of measurement and the required information of each parametric error separately.

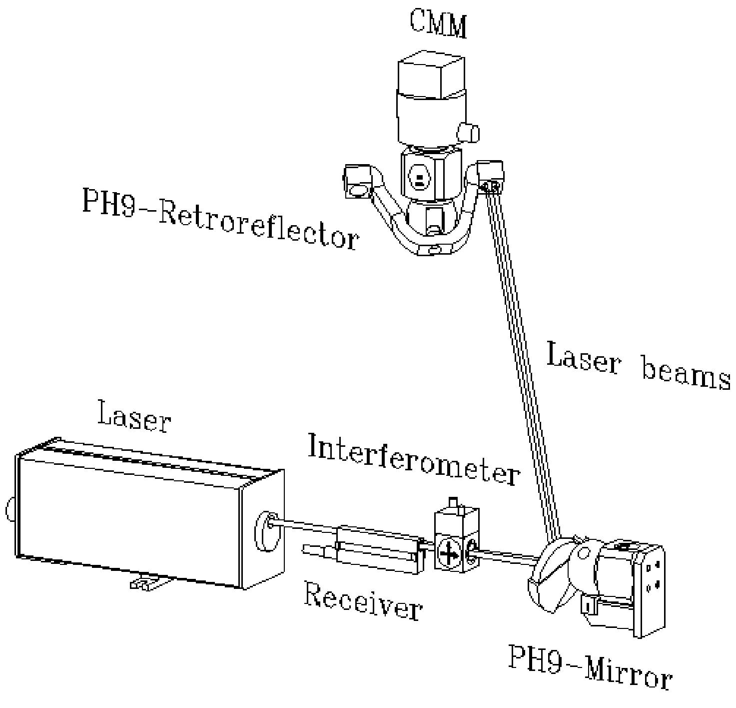

Figure 2. Principle of measurement of the new calibration method.

2.2 Measurement set up

A special measurement set up is developed to perform measurements in accordance with the described principle. This set up can be located in all corners of the workspace, making it possible to perform automated measurements from 8 positions. To keep sufficient free workspace the set up is always located outside the measuring range, however due to its size only larger CMMs are suitable for calibration (see figure 3).

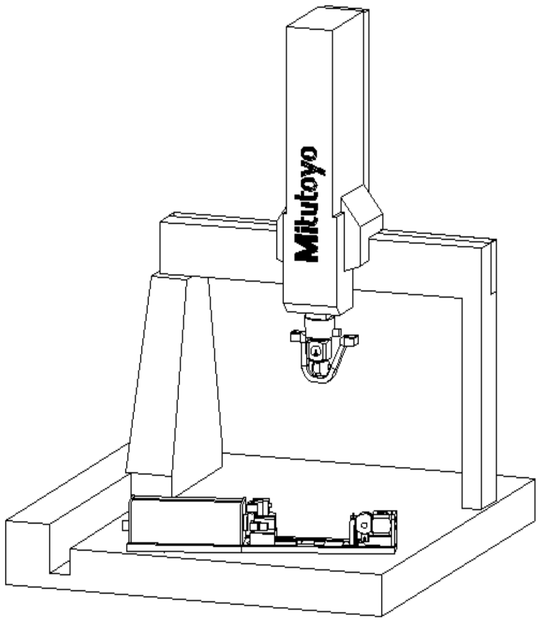

Figure 3. Measurement set up.

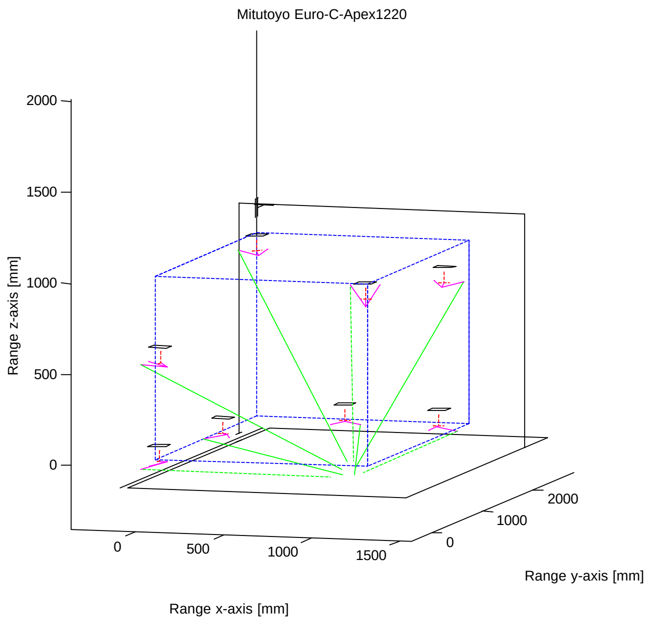

Figure 4. Predicted laser beam paths.

To define the location of the reflected laser beam, a mathematical representation of the beam path is derived. Mathematics describe a laser beam reflected by a mirror surface, which can rotate around two rotation axes located in space arbitrarily. Furthermore an estimation algorithm is developed to determine the location of the measurement set up in relation to the workspace of the CMM. This algorithm uses the input of three manually performed initialisation measurements along the CMM's axes. Combining both mathematical procedures enables prediction of the location of the reflected laser beam for each setting of the mirror respectively. Finally software controls the laser, probe heads and CMM to perform measurements.

By changing the orientation of the reflected laser beam, it is possible to measure at different locations within the measuring range of the machine. The measurement set up enables initialisation measurements close to single-axis, however all measurements are three-dimensional.

Figure 4 represents a simplified CMM and its workspace in combination with the initialisation measurements (dashdotted lines), predicted laser beam paths (solid lines) and accompanying retroreflector settings.

3 MINIMISING COSINE ERRORS

Due to different error sources the prediction of the laser beam is not perfect. Consequently the CMM is not moving in conformance with the orientation of the laser beam, resulting in cosine errors [8]. Investigation of the characteristics of the interferometer signal show that its power range can be modelled by a paraboloid, providing a maximum value to be used for optimisation.

At the start and end-position of a predicted measuring line, the CMM is moved corresponding a specific approach to find the optimum voltage of the receiver. Correspondingly by moving the machine between these optimised positions its displacement is parallel to the laser beam. In this way the effect of cosine errors is minimised, in contrast to the conventional method where the accuracy of the laser-path alignment is dependent on the qualities of the operator.

4 MEASUREMENT STRATEGY

The conventional set of measurements consists of single-axis and diagonal measurements with a laser interferometer, appended by single-axis measurements with straightness optics. This set of measurements is based on the kinematic structure of the machine and the ability to determine parametric errors by diagonal displacement measurements, e.g. [7][9][10]. If optical alignment is performed manually it is convenient to use straightness optics, however for the presented method this is unsuitable. The developed strategy is therefore based on the conventional set of measurements appended with linear interferometer measurements to determine straightness. Furthermore thermal effects are minimised by keeping a stable temperature in a controlled room.

For the presented method each measurement is influenced by multiple parametric errors, because all measurements are three-dimensional. Consequently redundant information about all parametric errors is required. That is, the set of measurements must cover the complete workspace of the CMM. However due to the measurement set up the data density is not equally divided. Near the mirror it is high and at the edge of the measuring volume it is low. Therefore automated measurements are performed from at least three corners of the workspace. Coming down to twice a displacement of the measurement set up.

It is possible to obtain higher accuracy by increasing the density of measuring lines or the number of locations from which automated measurements are performed.

5 VERIFICATION OF THE CALIBRATION

The final accuracy of a CMM is directly related to the quality of the calibration, as a result it is very important to analyse its performance. The result of the calibration is verified in three ways; first residuals between measured and predicted data are analysed, secondly parametric errors are compared with a conventional calibration and finally a CMM's (Euro-C Apex1220) accuracy is verified.

During calibration all parametric errors are estimated at once, according to a kinematic model of the machine. After this computation, residuals display the difference between measured and predicted positions. These residuals should be distributed randomly, because a trend points out disconformity between measured data and kinematic model. For the presented method it shows that this constraint is met.

Additionally a co-ordinate measuring machine is calibrated by means of the conventional and proposed method. Comparison of the estimated parametric errors revealed that differences are negligibly small even for straightness.

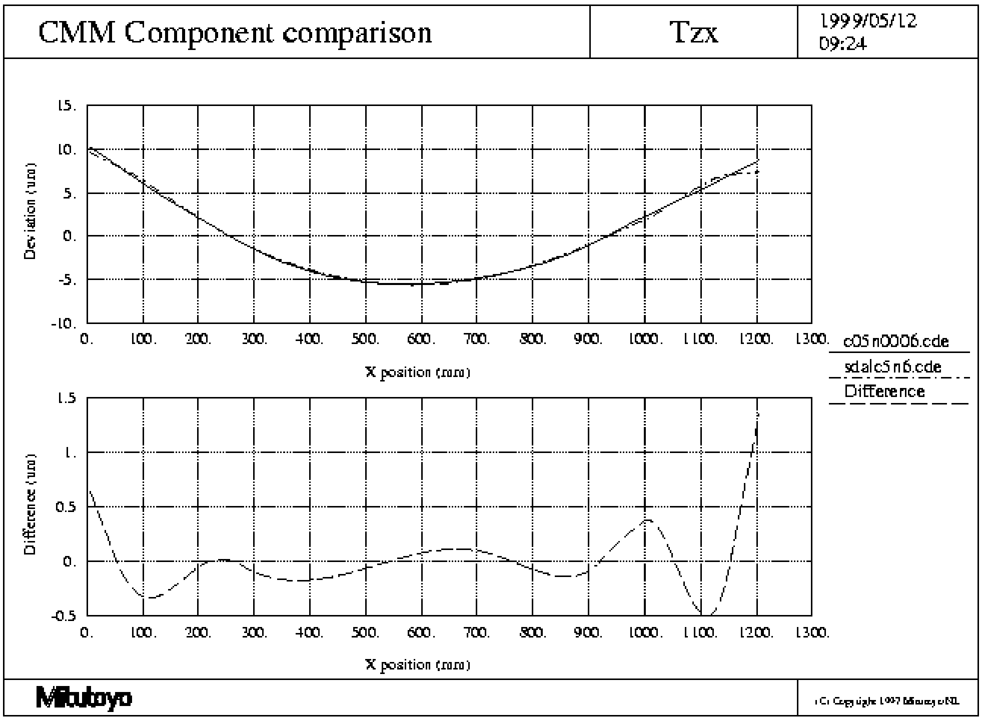

Figure 5. Parametric error comparison of Tzx.

Figure 5 shows comparison data of the vertical straightness of the X-axis estimated by the conventional and presented method. Tzx represents the estimated counterpart of the parametric error xtz.

To obtain a final verification of the CMM's accuracy, single-axis and volumetric measurements with linear interferometer or straightness optics are performed. Figure 6 displays the positional errors of a laser interferometer measurement in spatial diagonal direction. All inspection measurements show that the CMM performs within specification.

At the time of writing, multiple machines are already error compensated by the developed system. The results prove that the presented technique is a reliable alternative to volumetric calibrate larger size CMMs at their production stage.

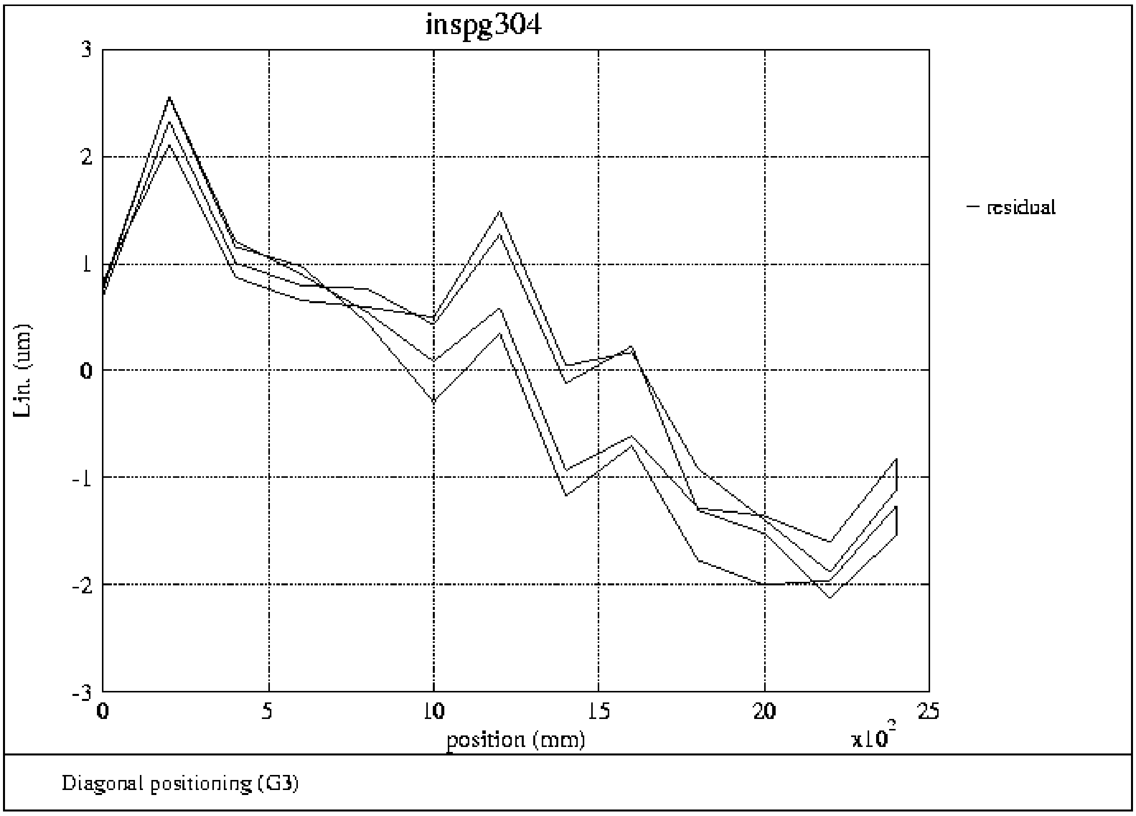

Figure 6. Spatial diagonal accuracy of a calibrated CMM (U3=4.9+5L/1000 [ìm]).

6 CONCLUSION AND RECOMMENDATION

A measuring system is developed, which enables automated geometrical calibration of larger size CMMs at their production stage. It shows that performing only spatial laser interferometer measurements provides a reliable method to link parametric errors of a CMM to its volumetric accuracy. Compared to the conventional method a comparable calibration result is obtained with less costs and personal effort. The total calibration time stays the same, only the effective working time for an operator decreases by approximately seventy percent.

It is recommended to automate the method furthermore by integrating a position sensitive detector, in this way the manually performed initialisation measurements become obsolete.

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