

Methods and Artifacts to Calibrate Large CMMs

L. Arriba¹, E. Trapet¹, M. Bartscher², M. Franke², A. Balsamo³,
G. Costelli⁴, S. Torre⁴, F. Kitzsteiner⁵, F. San Martín⁶

¹ TRIMEK, Spain; ² PTB, Germany; ³ IMGC, Italy; ⁴ DEA Brown & Sharpe, Italy;
⁵ Zeiss, Germany; ⁶ GPE, Spain

Abstract

Up to now methods using artifacts to inspect large coordinate measuring machines (CMMs) are suitable only for interim checks and verification [1,2]. For a full-scale error analysis of larger CMMs (at least one axis > 2 m) no readily applicable methodology exists so far, thus VDI and ISO have recently started activities yielding traceability of large CMMs. Regarding this background methods for a full-scale error analysis of large CMMs (calibration, error correction & performance tests) were developed under the EC funded SM&T Programme (project SMT4-PL97-2330). Methods are based on calibrated artifacts, which are described here: Light weight ball plates, disassemblable ball plates and disassemblable multi-ball bars. CMM manufacturers and users are testing methods and artifacts. Error models were extended to include non-rigid-body errors, typical of large CMMs (methods for error assessment and algorithms for numerical correction).

New artifacts, their justification, their design criteria

Three types of artifacts are studied to optimize their costs, calibration procedures, stability, and the error assessment processes. In all cases carbon fiber reinforced plastics (CFRP) is used to reduce weight, reach optimum stiffness and to avoid thermal effects. The new artifacts (Fig. 3, Fig. 4) surfaces are sealed to avoid humidity influences.

1. A **ball plate with carbon fiber rod structure** (Fig.1) giving compatibility with existing measurement and evaluation strategies, but being limited to 1.5 m x 2 m size. Fig. 2 shows the required 6 measurement setups on a horizontal arm CMM.
2. A **disassemblable ball plate with L-shape of carbon fiber tubes** (Fig. 3 and 4). The main advantage is the 2D-feature, resulting in a minimum of only six measurement setups for a full rigid-body error analysis, including some non-rigid-body errors.
3. A **disassemblable multi-ball-beam of carbon fiber pipes** (Fig. 4 and 3) made of the same structural elements as the L-shaped plate. It can be calibrated in situ, combining a length transfer (with self centering transfer apparatus and calibrated reference ball beam) and a two-position reversal technique (on CMM to be calibrated).

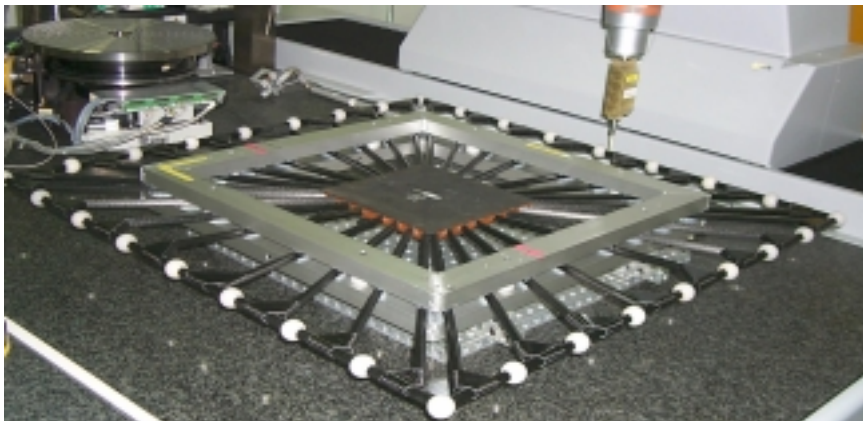


Fig. 1
Light weight ball plate made of carbon fiber rods and ceramic spheres (during its calibration with CMM and laser interferometer). Plates are calibrated by reversal techniques. Such plates are feasible up to 1.5 m x 2 m, limitations are mainly due to transport problems.

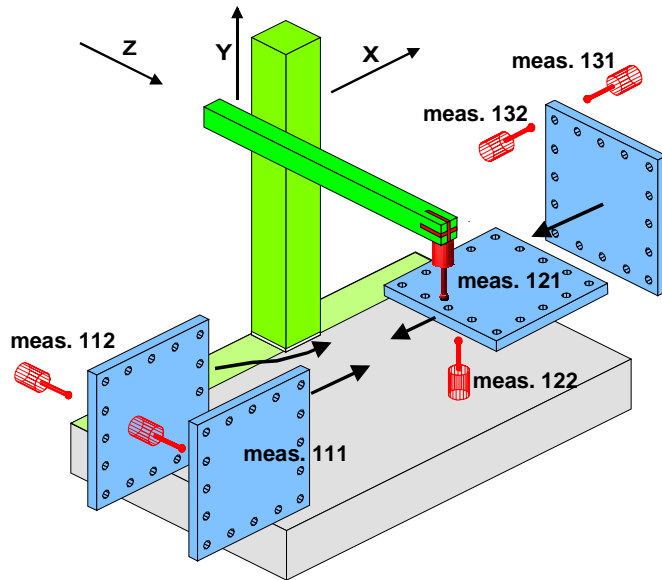


Fig.2
Required measurement setup to assess all rigid-body error components plus elastic column tilt with a ball/hole plate. Elastic column bending angle and elastic column straightness require the measurement of one more array line of balls/holes (e.g. in position 131). An error assessment can be as fast as 3 hours, not possible with 1D-artifacts.

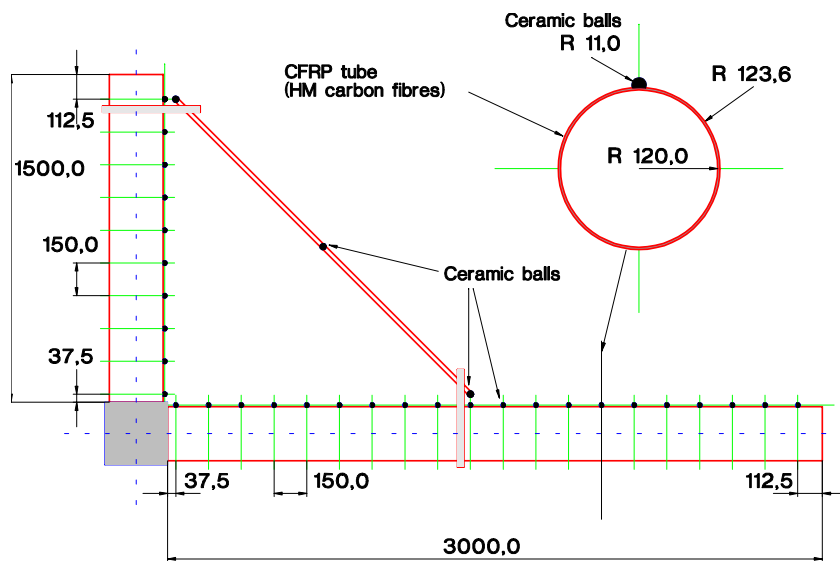


Fig. 3
Design of L-shaped artifact, composed of three segments, horizontal and vertical elements are pipes with weight-induced bending of $< 2 \mu\text{m}$ if supported in three points; the same number of measurement setups is required as for the ball plate in Fig. 1. The segments are calibrated like the disassemblable multi-ball-beam described below. (feasible up to 3 m x 2 m)

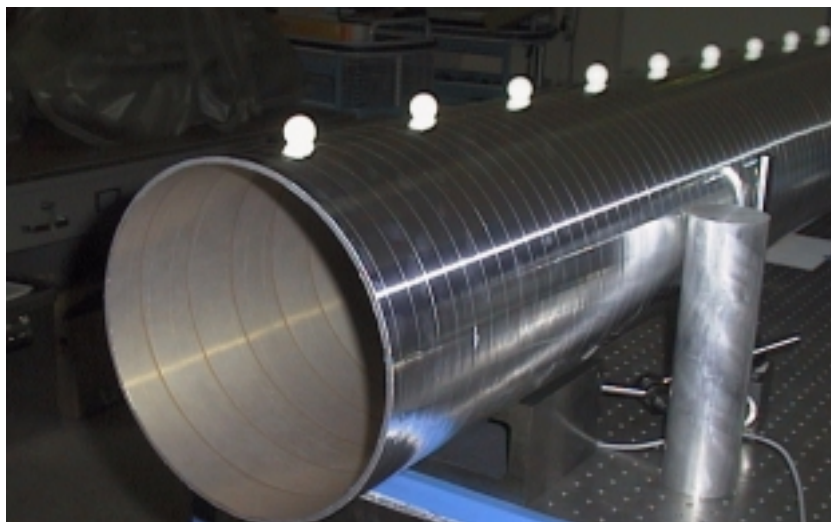


Fig. 4
View of a 3 m segment of a 6 m multi-ball-beam. The segments of the multi-ball beam are made identical with those of the L-plate, which can be composed from this tubes of an universal set, e.g. of 1 m, 1.5 m, 2 m, and 3 m modules. Multi-ball-beams are feasible up to 12 m and more (3 m segments).

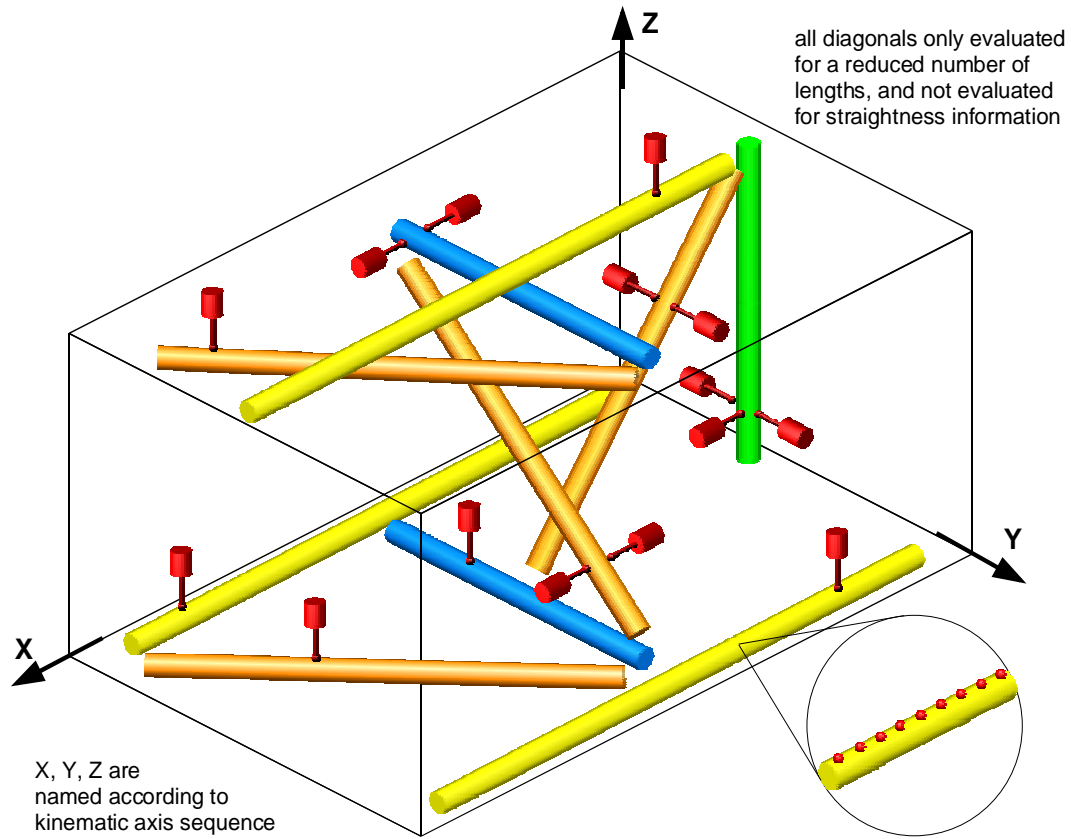


Fig. 5 Arrangement for 3D-calibrated multi-ball-beams to assess all rigid-body errors (minimum: 5 styli, 10 positions, 15 measurements). This concept requires more positions than the ball plate concept. Assessing non-rigid body errors requires two more positions.

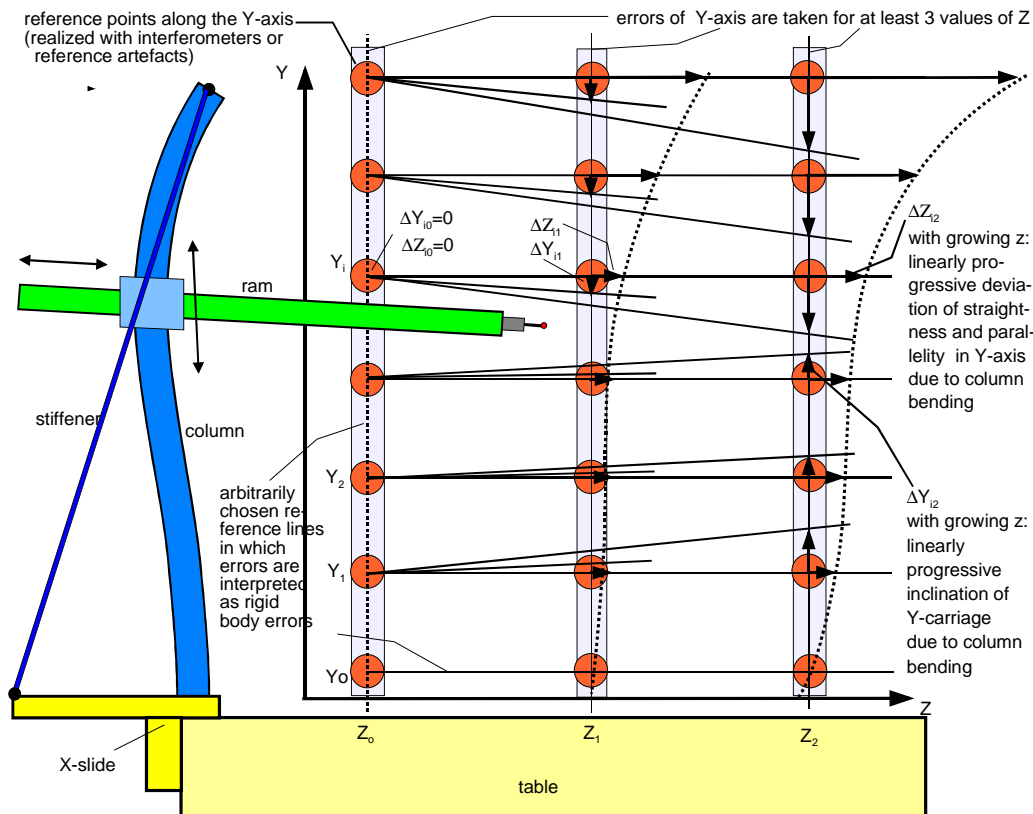


Fig. 6 Elastic errors of column straightness $y(z)$ and column bending angle $\alpha(z)$; these effects can be measured with a ball plate or a 3D-calibrated multi-ball beam, placed at three different distances from the column in the YZ plane.

Upgrading of geometry error models for large CMMs

Commonly used models describing the errors of a machine by 6 degrees of freedom of the slide of each machine axis of motion, are not sufficient for large CMMs. The study on horizontal arm machines within this project has shown three significant elastic effects:

1. **Elastic column tilt angle $xrx(z)$** due to changing momentum when moving the ram and consequent deformations in the X-slide bearings, the bearing suspension, in the X-slide itself, and in the column part which is below the lowest Y-slide position. $xrx(z)$ for a constant height y is a linear function of z . $xrx(z)$ does not vary with height y .
2. Column bending from changing momentum when moving the ram, causes a **rotation $yrx(y,z)$** due to bending of the column within the range of the slideway Y .
3. Column bending from changing momentum when moving the ram causes as well a **straightness error $ytz(y,z)$** which is in general independent from the rotation $yrx(y,z)$.

Data collected so far (e.g. $yrx(y,z)$: Fig. 7), indicate that elastic errors reproduce fairly well for different machines. Thus, for correction purposes, they need not necessarily be assessed for each machine. Fig. 6 shows how column bending angle and column straightness can be assessed. Column tilt $xrx(z)$ can be assessed by measuring the differential errors of length in Z-direction at two different heights y with the errors “column bending angle” and “column straightness” pre-corrected. Studies of the possible elastic errors of gantry-type CMMs were performed within the frame of this project. These studies yield a simple dominating effect: elastic roll in the first axis (X) depending in each position x linearly on the position of the second axis (Y). A suggestion for its quantitative assessment has been developed, proofs are underway.

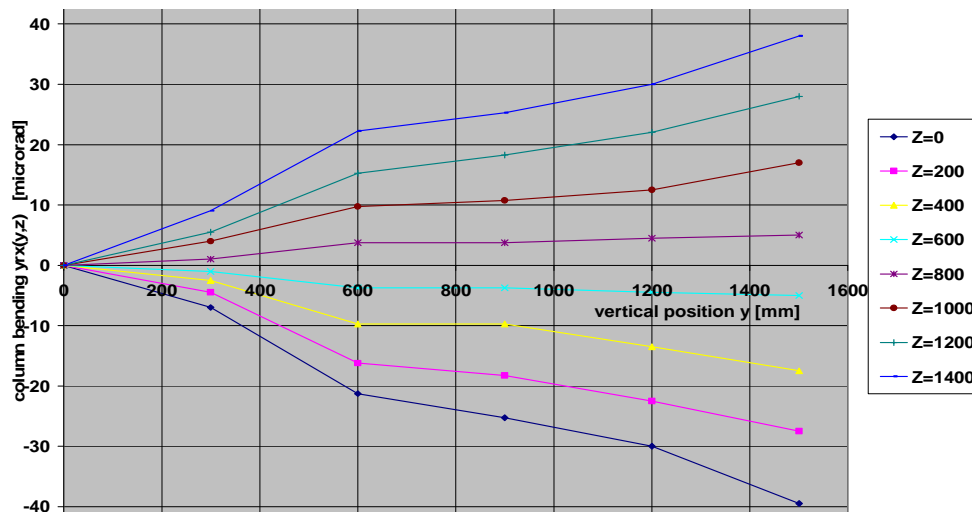


Fig. 7 Column bending angles as they depend on y (vertical coordinate axis), for different ram extensions z ; increase of angle is linear with z , and nonlinear with y (column tilt at column base already subtracted).

Conclusions

A set of artifacts optimized for different sizes of large CMMs has been developed and is being tested. Light weight ball plates are most economic and useful up to 5 m CMM axis length; 3D-calibrated multi-ball beams are slightly less economical and can be applied for virtually any CMM size. The artifacts can assess all 21 rigid-body errors (Fig. 2, 5), with 1-2 more positions they allow to assess non-rigid-body errors of large CMMs.

References

- [1] K. Busch, E. Trapet, F. Wäldele: *Simple Interim Check of Large Coordinate Measuring Machines*, European Production Engineering **18** (1994) 3-4
- [2] R. Corta, M. G. Cox, N. R. Dotson, D. R. Flack, A. B. Forbes, J. O'Donnell, G. N. Peggs, E. Prieto: *A large reference artefact for CMM verification*, NPL Report CLM **6**, May 1998