Physikalisch–Technische Bundesanstalt

EUROMET Key Comparison
L - K6

CMM 2-D Artifact: Ball Plate

Technical Protocol

Rev 2

1 Introduction

1.1.1 The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs). The RMOs are asked to organize Regional Key Comparisons to link the CCL KC to those NMIs that did not participate in the CCL KC.

1.1.2 At its meeting in 2002, the EUROMET TC Length decided to run such a Regional Key Comparison as a link to the CCL KC K6. In 2003, PTB was identified as pilot and organizer.

1.1.3 The procedures outlined in this document cover the technical procedure to be followed during measurement of the artifacts. The procedure, which follows the guidelines established by the BIPM[1], is based on the existing technical protocol document for the key comparison on small gauge blocks[2], long gauge blocks[3], CMM 1-D artifacts[4], and CMM 2-D artifacts[5].

[1] T.J. Quinn, Guidelines for key comparisons carried out by Consultative Committees, BIPM, Paris

[2] R. Thalmann, Calibration, of gauge blocks by interferometry - Instructions and technical protocols, OFMET, Wabern.

[3] A. Lewis, Calibration of long artefacts - Technical Protocol, NPL, Teddington.

[4] O. Jusko, Calibration of Ball Bars and a Step Gauge - Technical Protocol, PTB, Germany.

[5]M. Vielisid

2 Organization

2.1 Participants

2.1.1 A first list of National Metrology Institutes (NMIs) considering participation was compiles in the EUROMET TC.

2.1.2 The participating laboratories should:

2.1.3 Be able to calibrate a 420 mm steel ball plate (outer gauge), with 5x5 ceramic 22 mm in diameter balls and 83 mm pitch between ball centers. The centers spans a 332 mm x 332 mm grid.

2.1.4 All participants must be able to demonstrate independent traceability to the realization of the meter.

2.1.5 After agreeing on a final version of this protocol, each nominated participant must reconfirm its participation and approval of protocol. If for any of the above technical reasons a nominated laboratory is not able to participate, it must notify the pilot laboratory as soon as possible to reschedule the comparison and, eventually invite other possible participants.

2.1.6 By their declared intention to participate in this key comparison, the laboratories accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

2.1.7 Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.2 Participants

No.	COUNTRY	CONTACT PERSON / ADDRESS
1	CZECH REPUBLIC CMI	Vit ZELENY Czech Metrology Institute (CMI) V botanice 4 150 72 Praha 5 Czech Republic http://www.cmi.cz/ tel. +420 257 288 387 fax. +420 257 328 077 vzeleny@cmi.cz
2	DENMARK IPL	Prof. Leonardo de Chiffre Manufacturing Engineering and Management Produktionstorvet DTU – Building 424 2800 Kgs. Lyngby Denmark tel. +45 4525 4760 fax. +45 4525 0190 ldc@ipl.dtu.dk
3	FINLAND TUT	Prof. Heikki Tikka Tampere University of Technology Institute of Production Engineering Korkeakoulunkatu 6 33720 Tampere Finland tel. +358-3-3115 2719 fax. heikki.tikka@pe.tut.fi
4	GERMANY (Pilot) PTB	Otto Jusko Department Coordinate Metrology Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany Fon +49-531-592-5310 Fax +49-531-592-695310 Otto.Jusko@ptb.de
5	HUNGARY OMH	Edit Banreti National Office of Measures(OMH) Németvölgyi út 37-39 H-1124 Budapest XII Hungary tel. +36 1 458 59 97 fax. +36 1 458 59 27 E.Banreti@omh.hu

6	IRELAND NML	Jim O.Donnell National Metrology Laboratory Glasnevin IE-Dublin 9 Ireland Tel: Fax: jim.odonnell@enterprise-ireland.com
7	NETHERLANDS NMi	Rob Bergmans Netherlands Meetinstituut VSL B.V. (Nmi VSL) Department of Mechanics Shoemakerstraat 97 P.O. Box 654 2600 AR Delft Netherlands Tel.: 31 15 269 15 00 Fax: 31 15 261 29 71 e-mail: rbergmans@nmi.nl
8	POLAND GUM	Central Office of Measures (GUM) ul. Elektoralna 2 P.O. Box 10 PL-00 950 Warszawa Poland Tel: + 48 22 620 54 38 Fax: + 48 22 620 83 78 length@gum.gov.pl
9	PORTUGAL IPQ	Fernanda Saraiva Instituto Português da Qualidade Laboratório de Metrologia Rua António Gião, 2 PT-2829-513 Caparica Portugal Tel : +351 21 294 81 60 Fax :+351 21 264 81 88 fsaraiva@mail.ipq.pt

10	UNITED KINGDOM NPL	Andrew Lewis Centre for Basic, Thermal and Length Metrology National Physical Laboratory (NPL) Teddington ,Middlesex, TW11 0LW United Kingdom Tel: +44 20 8943 6124 Fax: +44 20 8943 2945 andrew.lewis@npl.co.uk
11	SWITZERLAND METAS	Dr. Ruedi Thalmann Swiss Federal Office of Metrology and Accreditation (METAS) Lindenweg 50 CH-3003 Bern-Wabern Switzerland Tel: + 41 31 32 33 385 Fax:+ 41 31 32 33 210 rudolf.thalmann@metas.ch

2.3 Form of comparison

2.3.1 . The calibration suitability of the artifact has been assessed by measurements at PTB prior to the start of the circulation of the artifacts. PTB will act as the pilot laboratory.

2.3.2 In the following section the timetable of the comparison is presented

2.3.3 Each laboratory will receive the artifacts according to the pre-agreed timetable.

2.3.4 All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 4 weeks of completion of the measurements by each laboratory.

2.3.5 Each laboratory has six weeks for customs clearance (if applicable), measurement and shipment to the following participant from the moment it is received at customs in his country till the following participant receives it at customs. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the time allocated to it. It guarantees that the standards arrive in the country of the next participant at the beginning of the next 6 week period.

2.3.6 If for some reasons, the measurement facility is not ready, the laboratory has to contact the pilot laboratory immediately and – according to the arrangement made – eventually to send the standards directly to the next participant before finishing the measurements or even without doing any measurements. If possible the laboratory will be sent the artifacts at the end of the comparison.

2.4 Timetable

Part.-#	NMI	Country	Period
1	TUT	Finland	2004-05-15 – 2004-06-30
2	METAS	Switzerland	2004-07-01 – 2004-07-19
3	OMH	Hungary	2004-09-16 – 2004-10-30
4	CMI	Czech Republic	2004-11-01 – 2004-12-30
5	PTB	Germany	2005-01-01 – 2005-02-28
6	IPL	Denmark	2005-04-01 – 2005-05-15
7	NPL	United Kingdom	2005-05-16 – 2005-06-30
8	NML	Ireland	2005-07-01 – 2005-08-15
9	NMi	Netherlands	2005-08-16 – 2005-09-30
10	IPQ	Portugal	2005-10-01 – 2005-11-15
11	GUM	Poland	2005-11-16 – 2005-12-30

2.5 Handling of Artifacts

2.5.1 Upon reception, the laboratory should confirm it to the pilot laboratory as well as to the sender laboratory by sending the form of Appendix A1. The artifact should be examined immediately upon receipt. The condition of the artifact should also be noted in the form.

2.5.2 The artifact should only be handled by authorized persons and stored in such a way as to prevent damage.

2.5.3 The artifact should be examined before dispatch and any change in condition during the measurement at each laboratory should be communicated to the pilot laboratory.

2.5.4 Please inform the pilot laboratory and the next laboratory via fax or e-mail when the artifacts are about to be sent to the next recipient.

2.5.5 Before and after the measurements, the artifact must be cleaned. Ensure that the content of the package is complete before shipment. Always use the original packaging.

2.6 Transport of Artifacts

2.6.1 It is of utmost importance that the artifact be transported in a manner in which they will not be lost, damaged or handled by unauthorized persons.

2.6.2 Packaging for the artifact has been made suitably robust to protect the artifacts from being deformed or damaged during transit. Notices in the boxes will state handling instructions in case the boxes have to be opened at customs. Notify to the airport personnel that the cases shall be towed on a palette in order to minimize the risk of damage.

2.6.3 The artifact should be sent via courier or delivery company. They should be marked as ‘Fragile’.

2.6.4 The artifact should be sent with enough time in advance as to have the following laboratory receive them at the nearest port or airport on the date that their period starts.

2.6.5 Until the first return of the ball plate to PTB (December 2004), the artifact is accompanied by an ATA – Carnet. Although this only needed by non EU participants, its presence should be checked.

2.6.6 Transportation and insurance to the following participant is each laboratory’s responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges upon receipt as well as for any damages that may have occurred within its country. The overall costs for the organization and for the devices are covered by the organizing pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

3 Description of the Standard

3.1 Artifacts

The measurement artifacts are the following:

Ball Plate

Make: KOBA

Serial Number:

Material: Steel frame with ceramic balls.

Nominal thermal expansion coefficient (as stated by the manufacturer):

$\alpha = 11.5 \times 10^{-6}\ K^{-1}$ at 20 ℃.

Dimensions (mm):

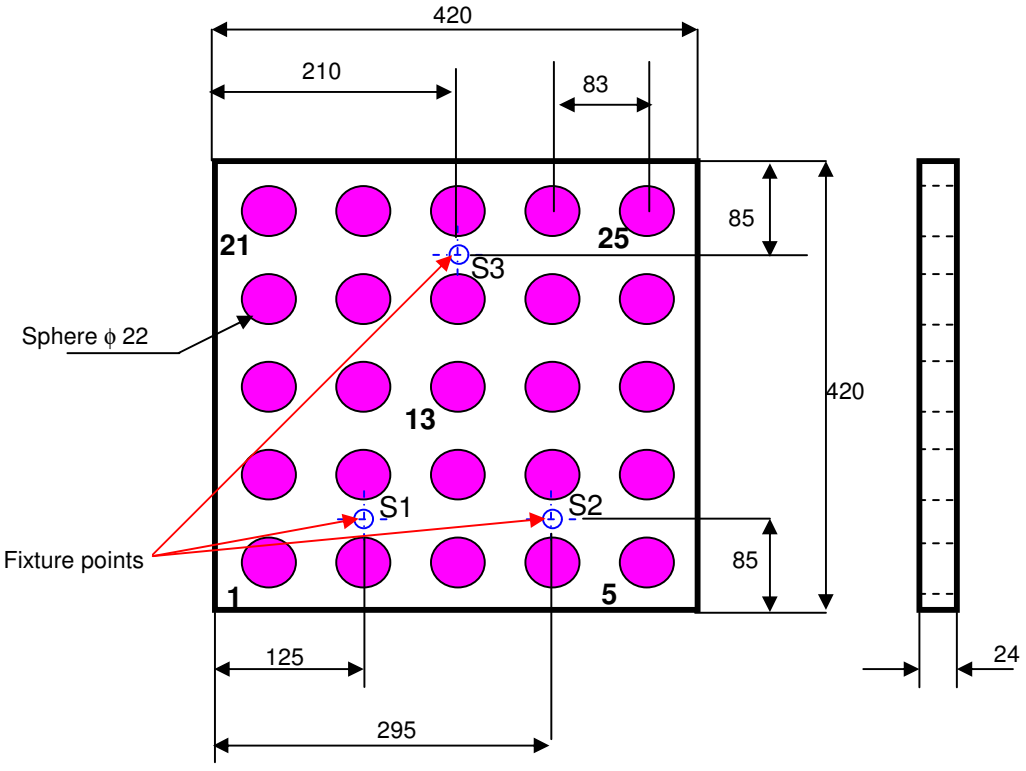


Figure 1. Ball plate description

4 Measurement instructions

4.1 Traceability

4.1.1 Length measurements should be independently traceable to the latest realization of the *mètre* as set out in the current "*Mise en Pratique*". This means that the length unit is transferred to the ball and bore plates with the CMM by one of the following methods: laser interferometer, gauge blocks, ball beams, ball bar or step gauges. Whatever the instrument or standard used, it should be traceable to the definition of the length unit through calibrations performed in house. Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

4.2 Measurands

4.2.1 *Ball Plate.-* The object reference plane is defined by the center of balls number 1, 5 and 21. The origin of object coordinate system is the center of ball number 1. The X-axis of the object reference system is defined by the line that passes through the center of ball number 1 and the center of ball number 5. The direction from the origin to ball number 5 defines the positive X-axis direction. The Y-axis is defined as the orthogonal line that passes through the center of ball number 1. The positive direction is from ball number 1 to ball number 21. The measurands of the ball plate are the X-Y-co-ordinates of each ball center with respect to the origin of object coordinate system (Fig.2) with the plate lying horizontally and fixed as described in section 4.3.3. Optionally the Z-coordinates can (and should) be reported, if possible, but they will not be the base of MRA/CMC – relevant analysis.

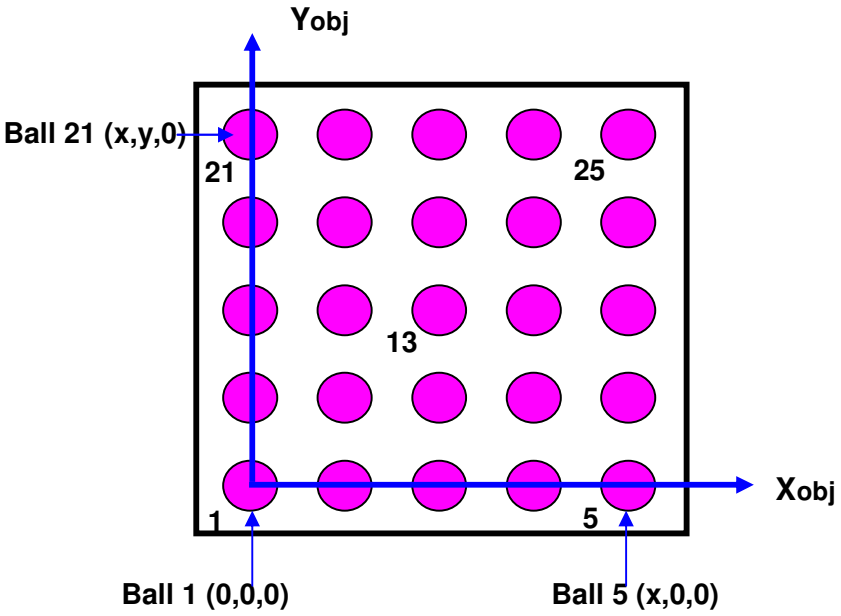


Figure 2. Ball plate coordinate system

4.2.2 The thermal expansion coefficient used should be the quoted values for each plate. Laboratories should report the temperatures at which the length measurements were made. Laboratories should only measure the artifacts at a temperature of (20 ± 0,3) °C.

4.3 Measurement instructions

4.3.1. Each laboratory is free to use his own measuring method. However, measurements should be reported in the object reference coordinate system described in 4.2. Appendix A5 describes one measurement method that can be used. Before measurement, the artifacts must be inspected for damage. Special attention should be paid to the measurement surfaces and balls. Any scratches other damages have to be documented. Appendix A1 contains a form that should be filled and sent upon reception quoting the state of the artifacts as received.

4.3.2. Before measurement, the plate and support must be cleaned. The balls have to be cleaned with special care individually as well as the measuring surfaces in the vicinity of all probing points.

4.3.3. Included with the ball plate there are three hemispherical supports which can be screwed to tapped holes in the plate. The proposed holes are marked by pilot.

4.3.4. No other measurements are to be attempted by the participants and the artifacts should not be used for any purpose other than described in this document. The artifacts may not be given to any party other than the participants in the comparison.

4.3.5. If for any reason a laboratory is not able to make all the measurements of one or both artifacts, it is still encouraged to report the rest of the results. Foreseeing this possibility, the laboratory may chose to make only the determination of the position of peripheral form elements, for example.

5 Measurement uncertainty

5.1 The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. Due to differences of equipment, methods and procedures applied between laboratories, a complete list of uncertainty sources to be taken in account may not be drawn. However, the following table quotes the usual measurement uncertainty sources. Additional sources may be added at the end of the table according to each laboratory's set-up, equipment, procedures and uncertainty estimation method, but it is expected that this additional source will not dominate the uncertainty budget.

Measurement uncertainty sources if employing *gauge blocks,* step gauges or laser interferometer for the length comparison on *calibration plates*

Uncertainty Source	**Uncertainty value**	**Uncertainty in Length**
short term reproducibility	µm	µm
drift of temperature in the plate	K	µm*L/m
drift of temperature in CMM	K	µm*L/m
deviation from linearity of the CMM's errors of position	µm	µm
uncertainty of the gauge block or step gauge length or laser interferometer	µm*L/m	µm*L/m
uncertainty of the length comparison (probing uncertainty)	µm	µm
uncertainty of the temperature difference during the length comparison	K	µm*L/m
uncertainty of the thermal expansion coefficient	K^{-1}	µm*L/m
Other contributions	µm	µm

6 Reporting of results

Results should be communicated to the pilot laboratory as soon as possible and within four weeks after the end of the corresponding laboratory allocated time period.

Appendix A2 should be filled quoting the state of the measurement surfaces of the artifacts; describing the measurement instrument, measuring technique, traceability chain, temperature variation and temperature measurement method.

Appendix A3 should be filled with the measurement results.

Finally the uncertainty budget must be stated by filling the form of Appendix A4. The uncertainty shall be stated as combined standard uncertainty with no coverage factor applied at the end. Length dependent terms should be left in terms of *l* (length)., and the combined standard uncertainty should be expressed as a quadratic sum of the form:

$$u_c(l) = (a^2 + b^2 \cdot l^2)^{½} \ ,$$

where *a* and *b* are real numbers, *l* is the length in mm and $u_c(l)$ is in μm.

The three forms should be filled and sent by mail service as well as by electronic mail to the pilot laboratory. The later means is to allow the pilot laboratory to collect the results as soon as possible. **In any case, the signed report must also be sent in paper form.** In case of any differences between the two messages, the paper forms are the ones considered to be valid.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyze the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in the BIPM Key Comparison Guidelines will be followed.

For comparison of the measurement results a reference value will be needed. As there is at present a lot of discussion about the calculation of reference values, the method for the calculation of the reference value will be fixed after the completion of the measurements.

A1. Receipt confirmation

FAX

To: **Dr. Otto Jusko**
PTB
Department "Coordinate Metrology"
Bundesallee 100
38116 Braunschweig

Fax: +49-531-695310 **Tel.: +49-531-59-5310**

e-mail: otto.jusko@ptb.de

From:

We confirm having received the standards of the EUROMET *key comparison L-K6 on ball plate* .

After visual inspection

- no damage has been noticed;
- the following damage must be reported:
  .....
  .....
  .....
  .....

A2. Measurement results

A2.1 Inspection of the measurement surfaces

Notes:

A2.2 Description of the measurement instrument

Make and type of instrument

(If you use a non-commercial or significant modified commercial equipment, please add drawings, explaining papers etc.)

Traceability path (gauge blocks, step gauge, laser interferometer.):

Description of measuring technique:

Range of artifact temperature during measurements & description of temperature measurement method:

A3. Measurement results

Measurements results of the ball plate

	Coordinates of the sphere centers in mm		
Sphere No.	**x**	**y**	**z**
1	0	0	0
2			
3			
4			
5		0	0
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			0
22			
23			
24			
25			

A4. Uncertainty of measurement

x_i	$u(x_i)$	v_i	$c_i = \partial l / \partial x_i$	$u_i(l)$ / nm

Combined standard uncertainty: $u_c(l) = \sqrt{\qquad^2 + \qquad \cdot l^2}$

A5. Proposed measurement method

A5.1 Probing the balls. The balls have to be measured as shown in figures 3 and 4.

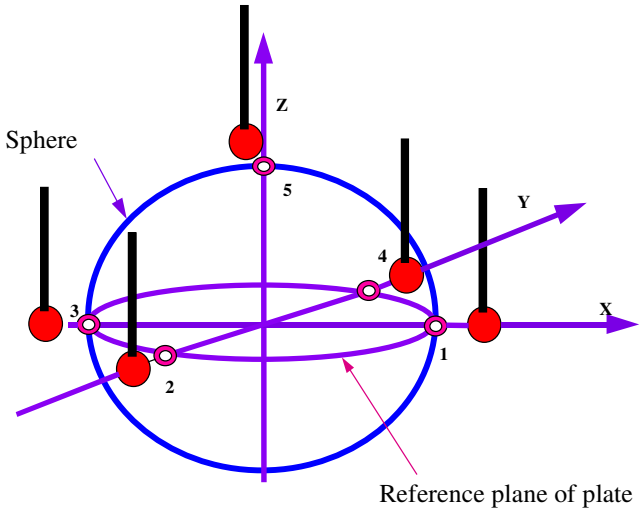
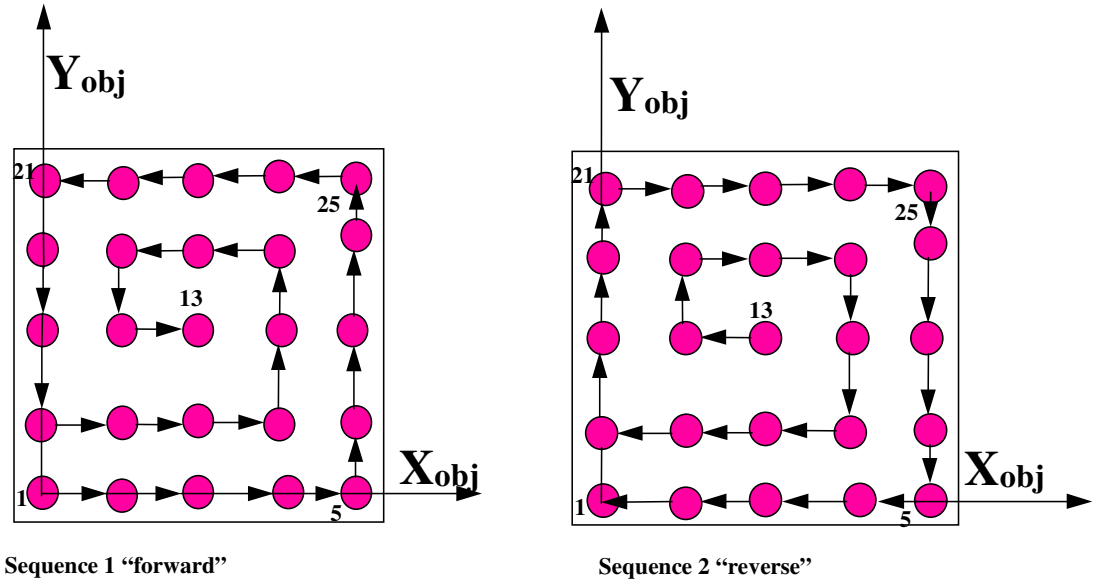


Figure 3. Measurement of solid spheres.

A5.2 Sequence of measurement

for the four plate positions is like a spiral (see **fig. 4** and **5**). The balls are measured proceeding spiral like from element to element from the plate's periphery to the plate's center. In all positions, measurements are started with the sphere or cylinder in the plate's zero point, and are continued following the positive X-axis. When the last element in the plate's center is reached, all elements are re-measured, starting with the element in the plate's center and reversing the sequence compared to the forward measurement.



Sequence 1 "forward" Sequence 2 "reverse"

Figure 4. Sequence of measurements for a ball plate position

A5.3 Plate positions

Four reversal measurements in a horizontal plane are performed. Fig. 9 shows the corresponding plate positions. In all 4 positions, the coordinate values of the center points of the balls are determined in the object coordinate system (see Fig. 3 and 4).

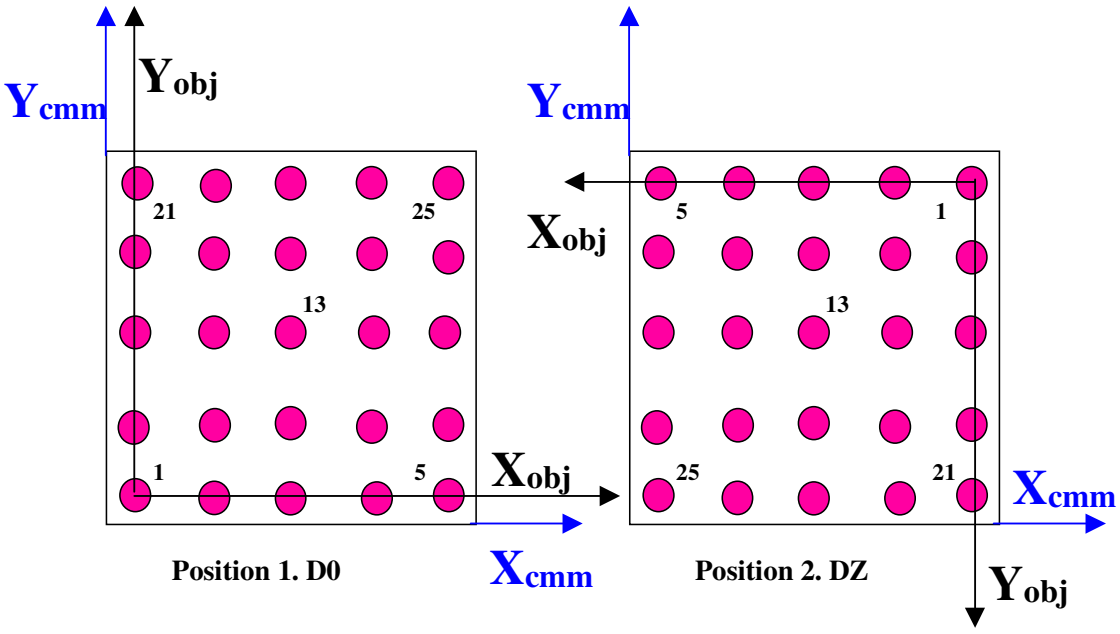
All reversal measurements should be performed in the same working volume of the CMM. The centers of the spheres have to coincide with the same points in the CMM's work space in all 4 plate positions. All spheres are measured with respect to the **plate's reference coordinate system** in all 4 positions.

Measurement 1 (position "D0") is obtained in the basic plate position, where the X-axis of the plate points in the direction of the CMM's first kinematic axis, the plate's Y-axis points in the CMM's second kinematic axis, and the Z-axis of the plate in the CMM's spindle axis.

Measurement 2 (position "DZ") is obtained by turning the plate 180° around the axis with respect to the basic position ("D0").

Measurement 3 (position "DY") is obtained by turning the plate 180° around the second kinematic axis of the CMM with respect to the basic position ("D0").

Measurement 4 (position "DX") is obtained by turning the plate 180° around the first kinematic axis of the CMM with respect to the basic position ("D0").



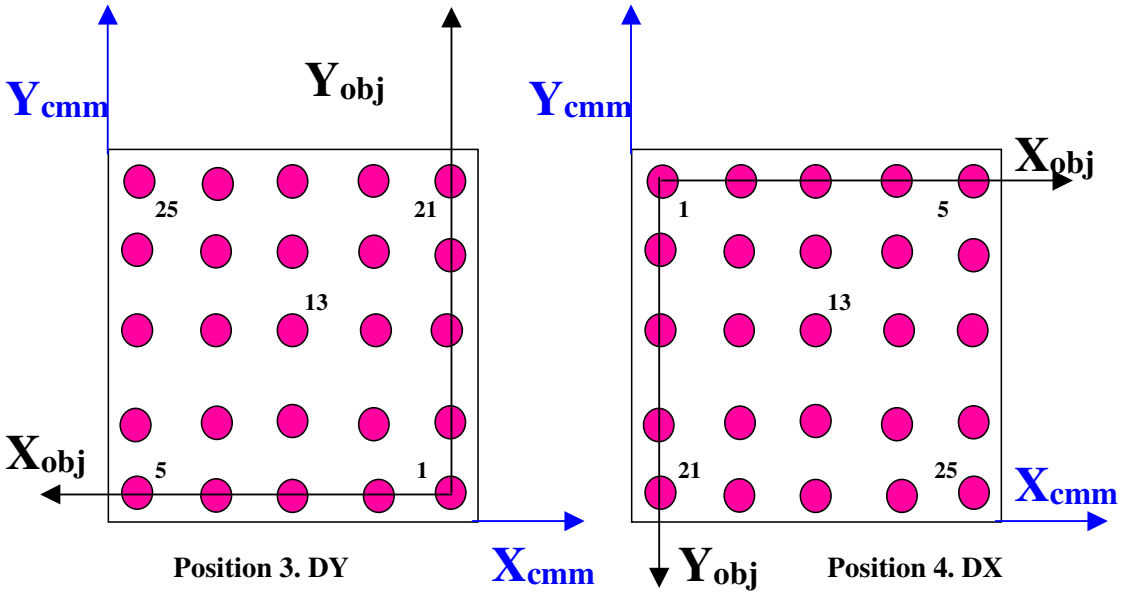


Figure 5. The four plate positions used for the reversal measurement

A5.4 Transfer of the unit of length.

Measure the distances between certain balls and compare the results with a reference measurement on a length standard. The comparison may be done with a laser interferometer, a gauge block or a step gauge. It consists on the determination of at least one center distance between 2 balls parallel to the **X-axis**, and at least one center distance between 2 balls parallel to the **Y-axis** of the plate (any combination of a column and a row is allowed) and comparing the results with the length of a gauge block, step gauge or a laser interferometer.