KOBA-step the Original

PRECISION STEP GAUGE + DATA-ANALYSIS SOFTWARE = A COMPLETE SYSTEM FOR MONITORING COORDINATE MEASURING MACHINES

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Step gauges for checking the accuracy of co-ordinate measuring machines

In industrial metrology, actual physical bodies of known length which can be contacted by mechanical sensors have an important part to play as reference standards when measuring geometrical parameters. They have become particularly important for assessing the accuracy of two and three-axis co-ordinate measuring machines which employ mechanical sensors. Checking the length measurements uncertainty has proved to be a highly informative and economical method for the acceptance testing and ongoing monitoring of co-ordinate measuring machines. In this case the step gauge can be used in an enormous variety of ways, giving, for example, the advantages of uni-directional and bi-directional targetting and of measurements from all the gauge faces along a line of measurement in succession while needing only a short time for preparation and measurement. Local errors can be detected in the co-ordinate measuring machine and characteristics can be derived for individual co-ordinate axes of the machine.

With the aid of the length measurement uncertainty, the manufacturer or user can specify and check the accuracy of a co-ordinate measuring machine to establish its suitability for length measurement. This fundamental task in metrology is of particular importance due to the fact that in practice the majority of measuring requirements are for the measurement of lengths.

"Length measurement uncertainty" is defined by VDI/VDE guideline 2617, part 2.1 as the uncertainty with which a co-ordinate measuring machine allows the precisely known distance between two points on two mutually parallel gauge faces situated in succession along a line of measurement to be remeasured. Fig. 1 shows a measurement of this kind being made, taking as an example an individual parallel gauge block with an outside length $L_e$ which is arranged obliquely in three dimensions and whose length is remeasured by successive contacts with the block with the probe head in positions I and II.

On the step gauge, spacings of different kinds for making test measurement are all available simultaneously, as follows:

- Outside dimension $L_e$ e.g. with the probe head in positions I and II (Fig. 2)
- Inside dimension $L_i$ e.g. with probe head in positions III and IV (Fig. 3)
- Rear-face to rear-face dimension $L_s$ e.g. with probe head in positions III and V (Fig. 3)
- Front-face to front-face dimension $L_s$ e.g. with probe head in positions VI and IV (Fig. 3)
- Positional length ($L_p$ of a gauge face from the datum gauge face, e.g. with probe head in positions VI and 0 (Fig. 3)

The illustrations show only one of many options available for each type and size of spacing. In magnitude, the differences between the length value $L_a$ indicated by the co-ordinate measuring machine or printed or displayed by its output processor and the true value $L_r$ of the measurement uncertainty $U$.

What this means is that $L_a$ can be both larger and smaller than $L_r$.

The value of the length measurement uncertainty is generally given in the form of a length-dependent formula: $U = A + K \cdot L$.

A distinction should be made between the figure $U_1$ specified for one-dimensional test measurements along a co-ordinate axis (with terms $A_1$, $K_1$, $B_1$), the figure $U_2$ for two-dimensional test measurements made diagonally in a co-ordinate plane (with terms $A_2$, $K_2$, $B_2$) and the figure $U_3$ for three-dimensional test measurements made diagonally in the three-dimensional space defined by the co-ordinates (with terms $A_3$, $K_3$, $B_3$).
Graphic representation and analysis

Length measurement uncertainty plot

For the purposes of graphic analysis, the differences $\Delta L = L_a - L_r$ which are found are plotted, with the correct signs, for the individual measured lengths and runs in a length measurement uncertainty grid (Fig. 4). The top and bottom boundary lines produce a funnel-shaped outline with the neck of the funnel measuring $2A$ ($A$ = figure specified by manufacturer for length measurement uncertainty irrespective of length). 95% of all the test measurements must lie within or on the boundaries. A quantitative analysis is made simply by counting the number of measurements which lie outside the boundary lines.

Gauge face position plot

With the step gauge it is also possible to test the positions $L_p$ of the gauge faces as distances from the datum face. If the relevant length errors $\Delta L_p$ given by position measurement in line with VDI guideline 2617 Part 3 are entered in a plot, then it is possible to see both the position of the test length and also the sequence if for example the measurement points in a run are connected by straight lines. With a set of individual gauge blocks this is not possible because they do not have any true common reference point and are not situated on a measurement line. For analysis use is made of a gauge face position grid (Fig. 5) (similar to the length measurement uncertainty grid). The outline is symmetrical and similar in shape to a butterfly with a width across the waist of $1A$. The parameters in this case correspond to the appropriate figures $A_1$, $K_1$, $B_1$ and so on. As this grid is moved along the measured length $L$, at least 95% of all the measurements must always lie within or on the boundary lines, meaning that all the measurement points must do so consistently whatever the position of the waist. This ensures that any pairing of two gauge faces (even from different runs) in the form of outside, inside or face-to-face dimensions will also lie inside the funnel of the length measurement uncertainty grid. Thus, the grid forms a combined graphic expression of both the equations given above for all points of measurement.

Comparison between the test standards gauge blocks and step gauges

Apart from the step gauge, the reference standards which lengths are known with the greatest accuracy are parallel gauge blocks. These however are relatively flexible and have to be mounted at the AIRY points (symmetrical spacing $a = 0.57735 \cdot L$) so that they are free of bending moments if this parallelism of the gauge faces is to be maintained. The gauge blocks for the individual test lengths can be individually placed one behind the other for shorter lengths and next to one another for longer lengths. However, when this is done there is no way of obtaining the different gauge points along a line of measurement which are desirable for measurement purposes.

Special features and advantages of the KOBA-step

The step gauge is of castellated configuration and in it a large number of forward and backward facing gauge faces are lined up along a single line of measurement. This line of measurement is the same for measurements between any faces and the position of the workpiece, that is to say the orientation of the carrying body, only has to be determined once to find this line. There are numerous possible combinations in various positions along the measurement line, that actual number of different interface dimensions for a step gauge with 26 castellations (= KOBA-step with a nominal size of 1020 mm) being 1326.

The special feature of the KOBA-step step gauge is the fact that the actual gauge points are situated on the neutral fibre of the carrying body and this means that there are no first-order changes in length if the state of bending changes. The configuration of the carrying body and the fact that the line of measurement is situated on the neutral fibre prevents any increase in the distance between the gauge faces at the points where the carrying body is supported and prevents them from moving closer together at intervening points. In the KOBA-step step gauge, which is neutral in bending, cylindrical gauge blocks are fixed in position individually in an internal longitudinal groove formed in a rugged steel carrying body of square section (55 x 55 mm). The axis of the gauge blocks is situated on the fibre of the carrying body which is neutral in bending and they form a series of castellations. The arrangement which has been adopted provides excellent protection for the gauge faces. The strength of the carrying body and the fact that the lengths do not vary if there are changes in the bending to which it is subject mean that the KOBA-step step gauge can be mounted in a wide variety of fashions, e.g. cantilevered with so-called zero position support or with support at the Besselpoints.
Fig. 2: Castellated step gauge arranged obliquely in three dimensions on the table of a co-ordinate measuring machine, with an outside length $L_e$ being measured.

Fig. 3: Step gauge arranged obliquely in three dimensions on the table of a co-ordinate measuring machine, showing measurement of an inside dimension $L_i$, an outside dimension $L_s$, or of the position $L_p$ of a gauge face as a distance from the datum face.

Fig. 4: Length measurement uncertainty grid with funnel-shaped boundary lines, for the formula
$$U = A + K \cdot \frac{L}{B}$$
with the possibility of different plots for $U_1$, $U_2$, $U_3$ which represent one, two and three-dimensional length measurement uncertainties.

Fig. 5: Sliding gauge face position grid of symmetrical butterfly-shaped configuration to represent the length measurement uncertainty
$$U = A + K \cdot L \leq B$$
with the possibility of different plots for $U_1$, $U_2$, $U_3$ which represent one, two and three-dimensional length measurement uncertainties.
Accessories

The range of accessories available which are needed for use with the step gauge, such as swivel support, and base allows the gauge body to be mounted on the co-ordinate measuring machine in such a way as to be free of torsion. A support of this kind produces a particularly stable connection between the step gauge and the table of the co-ordinate measuring machine (Fig. 7, 9 and 10).

The combination of the step gauge and its accessories produces a complete system for making an overall check on the co-ordinate measuring machine. One particularly important point is that the procedure of checking the co-ordinate measuring machine can be carried out fully automatically under computer control.

Traceability

Since the acceptance or refusal of a co-ordinate measuring machine may depend on the outcome of the length measurement uncertainty test, it is advisable always to use officially calibrated testing equipment in order to avoid unpleasant surprises and wrong interpretations. The KOBA-step step gauge is available with both DKD calibration-certificate (German Calibration Service-DKD) and Works Calibration.

Below are the length measurement uncertainties which can currently be achieved with the step gauge up to 1020 mm:

DKD: \[ U = 0,10 \, \mu m + 0,5 \cdot 10^{-6} \cdot L \geq 0,12 \, \mu m \]

Works Calibration: \[ U = 0,3 \, \mu m + 0,8 \cdot 10^{-6} \cdot L \] (length)

Recalibration

As is normal with all measurement standards, the KOBA-step step gauge should be recalibrated after a certain period. We recommend the following recalibration intervals:

First recalibration after one to two years and each successive recalibration after two to three years.

Alignment of the KOBA-step

To define the position and orientation of the KOBA-step resp. the measuring line within the measuring volume, we recommend proceeding as follows:

As the carrying body with the fixed cylindrical gauge blocks has been designed symmetrically to both sides, one of the external side surface and the upper external surface at the end of the large U-groove can be used for the alignment.

Any points which are as large as possible can be sensed at the side surface and at the upper external surface likewise. Both planes so defined are squared off mathematically. A parallel line 27,5 mm to the side surface and 30 mm to the upper surface is the measurement line situated on the neutral fibre.

It is also possible to use both ends of the 7 x 10 mm interior groove for the alignment and proceed in a similar way as mentioned before. The distance from the wall of the groove and the floor of the groove to the line of measurement is 5 mm in both directions.

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Cross drills for easy contacting of the measuring faces.

Fig. 6: Alignment of the KOBA-step at the contours or in the longitudinal groove.
Fig. 7: KOBA-step aligned horizontally along the X-Y plane diagonal, approx. 500 mm above the table, stylus probe vertical. Accessory: Base and swivel support.

Fig. 8: KOBA-step aligned along the X-axis (lying flat on the table with no accessories used), stylus probe vertical.

Fig. 9: KOBA-step aligned horizontally along the XY-diagonal plane, same accessory as above, turned round 90°, stylus probe horizontal; Contacting through crossdrills.

Fig. 10: KOBA-step aligned vertically along the Z-axis (standing in the base), stylus probe horizontal.
Practical Use

Practical experience in using the KOBA-step step gauge for checking the accuracy of co-ordinate measuring machines and assessing and interpreting the results has demonstrated the usefulness and potentially high information yield of the "length measurement uncertainty" method. The advantage lies in the fact that the measurement is carried out at precision gauge faces using the normal gauging procedure and in the main, the machine manufacturer’s standard processing software. Since the unidirectional and bi-directional gauging of inside and outside dimensions, dimensions between similarly orientated surfaces, and successive dimensions from a given point occur even in the routine measurement of work pieces and since the measurements which have been obtained can be correlated with one another as desired even after the event, it is good idea to make full use of the opportunities offered by the step gauge. What is more, a series of measurements at all the gauge faces in succession provides a large amount of interrelated information and requires only a short time for measurement.

Since the length measurement uncertainty characteristic very much depends on the geometry of the co-ordinate measuring machine, the lines along which measurements are made should be as follows:

- 3 to 4 measurement lines which are diagonal in three dimensions (i.e. along the diagonals of an inscribed cube – at a gradient of approximately 35° – or along the diagonals of the cuboid representing the measured space).
- 2 diagonal lines of measurement in each co-ordinate plane (i.e. along the diagonals of a square – at a gradient of 45° – or the diagonals of a rectangle).
- At least one line of measurement parallel to each co-ordinate axis.

At least 18 suitable lines of measurement have to be selected in order to arrive at a complete definition of the 18 geometrical cuboid characteristics of the entire measurement volume.

It has to be stressed in particular that reliable measurement results for the complex system cannot be achieved unless the stylus probes are included. Checking of the co-ordinate measuring machine without mechanically contacting, i.e.: without using a probe, will therefore not result in an comprehensive statement about the accuracy of the measuring machine.
Another KOBA-step application area:
**Conducting formal acceptance procedures and monitoring the precisions of machine tools and robotic dimensional-gauging systems**

The step gauge KOBA-step may be used for checking the positioning accuracies of machine tools and articulated-arm robotic dimensional-gauging systems, an application area where they offer the same elegant approach and speed as in checking co-ordinate measuring machines. The accessory items required here are those described above, a swivel support and base.

Regular use of the KOBA-step for monitoring dimensional-gauging precisions of machine tools is essential to total quality assurance. Total quality assurance demands more than mere precision dimensional gauging of finished work and components; regularly monitoring the dimensional-gauging precisions of the machine tools employed in their fabrication is indispensable. Finished products must be machined to within prescribed dimensional tolerances if they are to pass final acceptance checks. Regular monitoring of machine tool dimensional-gauging precisions provides valuable information on the degrees to which work/component dimensional tolerances are being maintained in machining operations.
**Standard nominal lengths**

<table>
<thead>
<tr>
<th>nominal length (mm)</th>
<th>number of gauge faces</th>
<th>overall length (mm)</th>
<th>weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>420</td>
<td>22</td>
<td>480</td>
<td>6.5</td>
</tr>
<tr>
<td>620</td>
<td>32</td>
<td>680</td>
<td>9.5</td>
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<tr>
<td>1020</td>
<td>52</td>
<td>1080</td>
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<tr>
<td>1540</td>
<td>78</td>
<td>1600</td>
<td>23.0</td>
</tr>
<tr>
<td>2020</td>
<td>102</td>
<td>2080</td>
<td>30.0</td>
</tr>
</tbody>
</table>

The nominal length of a step gauge is the distance from the first gauge face to the last gauge face. Special sizes on enquiry, at present available with length up to 2500 mm.

**Contents of sets**

**Set N° 5/420**
Contents: 1 off Step gauge, nominal length 420 mm
- 2 off fixing clamps
- 1 off swivel support for 420 mm
- 1 off Base size 1
housed in storage box

**Set N° 5/620**
Contents: 1 off Step gauge, nominal length 620 mm
- 2 off fixing clamps
- 1 off swivel support for 620 mm
- 1 off Base size 1
housed in storage box

**Set N° 5/1020**
Contents: 1 off Step gauge, nominal length 1020 mm
- 2 off fixing clamps
- 1 off swivel support for 1020 mm
- 1 off Base size 1
housed in storage box

**Set N° 5/1540**
Contents: 1 off Step gauge, nominal length 1540 mm
- 2 off fixing clamps
- 1 off swivel support for 1540 mm
- 1 off Base size 2
housed in storage box with 2 transport cases

**Set N° 5/2020**
Contents: 1 off Step gauge, nominal length 2020 mm
- 2 off fixing clamps
- 1 off swivel support for 2020 mm
- 1 off Base size 2
housed in storage box with 2 transport cases

Following characteristics identical for all lengths listed:
- Cross-section of holder: 55 x 55 mm
- Cross-section of cylindrical gauge blocks: 10 mm diameter
- Length of castellations: 20 mm
- Space between castellations: 20 mm

The step gauge KOBA-step can be aligned with all requested orientations – horizontally, vertically, diagonally and obliquely. With the swivel support angles can be set from −50° to +50° in steps of 5°. The base may be used as a holder for the swivel support as well as for the vertical alignment of the KOBA-step.
### Calibration Certificate

The calibration certificate documents the system (SI) and the realization of the units of measurement according to the International System of Units (SI). The DKD is signatory to the multilateral cooperation (ILAC) for the mutual recognition of calibration certificates. The calibration has been solely performed by starting from the surface 0 of the step gauge. The calibration object is a KOBA step gauge calibrated on a three-dimensional coordinate measuring machine.

#### Calibration Conditions
- **Date**: 10.04.2009
- **Mittlere Temperatur**: 20,01°C
- **12 Stunden im Messraum gelagert.**
- **Der Kalibriergegenstand wurde zum Temperaturausgleich vor der Kalibrierung mindestens 2 Stunden vor der Kalibrierung in den Messraum gebracht.**

#### Calibration Procedure
1. **Berechnung der Tiefe der Messflächen.**
2. **Berechnung der Mittenabstände der Messflächen zur Messfläche 0.**
3. **An dem Stufenendmaß wurden die Mittenabstände der Messflächen zur Messfläche 0 kalibriert.**

#### Measurement Results

<table>
<thead>
<tr>
<th>Surface</th>
<th>Measurement</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59,93786</td>
<td>0,00000</td>
</tr>
<tr>
<td>2</td>
<td>60,01603</td>
<td>0,00000</td>
</tr>
<tr>
<td>3</td>
<td>60,01196</td>
<td>0,00000</td>
</tr>
<tr>
<td>4</td>
<td>60,01603</td>
<td>0,00000</td>
</tr>
<tr>
<td>5</td>
<td>60,01196</td>
<td>0,00000</td>
</tr>
<tr>
<td>6</td>
<td>60,01603</td>
<td>0,00000</td>
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<tr>
<td>7</td>
<td>60,01196</td>
<td>0,00000</td>
</tr>
<tr>
<td>8</td>
<td>60,01603</td>
<td>0,00000</td>
</tr>
<tr>
<td>9</td>
<td>60,01196</td>
<td>0,00000</td>
</tr>
</tbody>
</table>

**Note:** The alignment in space was carried out by taking the top surface of the step gauge. The reference coordinate system of the step gauge was generated as follows:
- **Die Raumausrichtung erfolgte über die Deckfläche des Stufenendmaßes.**
- **Die Ebenenausrichtung erfolgte über die Seitenfläche des Stufenendmaßes.**
- **Die Lage der Antastpunkte ist aus Seite 6 ersichtlich.**

**Check:** The calibration object is a KOBA step gauge calibrated on a three-dimensional coordinate measuring machine. The step gauge was calibrated on a three-dimensional coordinate measuring machine.

**Reference:**
- **D - 73430 Aalen Gartenstraße 133**
- **D - 99999 Musterhausen**

**Additional Information:**
- **Mustermann GmbH**
- **eumetron GmbH**
- **Carl Zeiss PRISMO SACC (serial no. 130288)**

**Contact Information:**
- **Telefon: (0 73 61) 37 03-0**
- **Telefax: (0 73 61) 37 03-29**
- **www.eumetron.de**
Ideal
Standard design with gauge faces of ceramic

Advantages:
• corrosion resistant
• Stable in size
• less cleaning
• coefficient of expansion similar to steel
• wear resistance similar to carbide

Existing step gauges with cylindrical steel gauge blocks can be exchanged against ceramic. However, a re-calibration is necessary then.

Data-Analysis Software
An evaluation software designed to suit your requirements is available. The software was developed by

ITI
Ingenieurbüro für Technik und Informatik GmbH
Ellerhoop 6
DE-22885 Barsbüttel
Tel.: 0 40 / 67 08 10 46 · Fax: 0 40 / 67 08 10 47
e-mail: iti-gmbh@t-online.de

For further information please contact us direct.
KOBA-step *mini*

System for the calibration and monitoring of multi-sensor measuring instruments and coordinate measuring instruments of small measuring volume

**Special features**

The KOBA-step *mini* is a step gauge of the "KOBA-step" type but with harmoniously reduced cross-section and resized gauge block distance according to the measuring length and measuring task. The methodical advantages such as embedding of the cylindrical gauge blocks in the neutral fibre of the carrying body and the good access from three sides have been maintained. The length and distances of the gauge blocks were reduced to 10 mm according to the total lengths which allow to recognize local errors of the measuring instrument. The cylindrical gauge blocks are made of zirkonia ceramic thus free of corrosion and wear. The system is completed by the swivel support included in the delivery and by which the KOBA-step *mini* can be mounted horizontally, vertically or in the volume. The traceability to the National Length Standard is guaranteed by works calibration or through DKD or PTB.

**Scope of supply:**

KOBA-step *mini* with probing elements in zirkonia ceramic, base and swivel mechanism for positioning from 0° to 90° (horizontally or vertically) as well as aluminium storage case

**Standard lengths**

<table>
<thead>
<tr>
<th>Nominal length mm</th>
<th>Number of castellations/probing faces</th>
<th>Division mm</th>
<th>Overall length mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>11/22</td>
<td>10</td>
<td>220</td>
</tr>
<tr>
<td>310</td>
<td>16/32</td>
<td>10</td>
<td>320</td>
</tr>
</tbody>
</table>
For the first time, this gauge block combines the advantages which step gauges offer the user with the ability to meet the stringent metrological demands which a precision measurement standard has to meet:

- Available with various standard nominal lengths (210, 310, 420, 620, 1020, 1540 and 2020 mm) with even steps (castellation/gap = 10/10 mm, from 420 mm = 20/20 mm), also with different standard lengths and uneven steps (however, castellation = 10 mm, from 420 mm = 20 mm) for an optimal adjustment to the measurement task.
- Stainless finish guaranteed by special surface treatment.
- The gauge faces used are the specially machined end faces of cylindrical gauge blocks which are inset solidly into position in a groove by a special process.
- Gauge faces lapped for correct sensing.
- Carrying body specially aged for longterm stability.
- Solid connection between the cylindrical gauge blocks with gauge faces and the carrying body.
- Cylindrical gauge blocks deeply inset to protect them against damage, length 20 mm.
- Gauge faces conically reduced to 5 mm diameter, hence easy to clean.
- The centres of the gauge faces are located on the fibre of the carrying body which is neutral in bending. As a result changes in bending stress due to different horizontal or inclined or vertical orientations have an effect on the distances between the gauge faces which is so small that it can be ignored completely.

Because of the configuration adopted, the bending characteristics in the two principal planes are identical, and it is therefore equally possible for the gauge block to be orientated with the groove facing upwards (e.g. for vertical quills) or to one side (e.g. for horizontal quills) or downwards (e.g. for underfloor measuring machines with vertical quills operating from below). The measurements to determine the position of the carrying body in space can be carried out on the precision-machined rectangular groove.

- The longitudinal grooves in the side faces allow a wide variety of orientations and mounting methods on the table of the machine.
- The material of the carrying body determines its expansion characteristics \( \alpha = 11.5 \cdot 10^{-6}/°\text{C} \).
- The accuracy required is of a standard not achieved hitherto and is ensured by the use of a special laser interferometer comparator which gives the precise position of each gauge face. The numerical value (Actual value according to the Calibration chart) representing the position is not generally a whole-number decimal and qualifies immediately to direct the co-ordinate measuring machine and resp. for the evaluation of the length measurement uncertainty.
- Additional reliability in everyday use because the length of each individual cylindrical gauge block is known and does not vary and must be re-measured accurately by the co-ordinate measuring machine itself with the step gauge in any position and orientation.
- Cross drills between the castellations for easy sensing of the measuring faces.

References:

[1] VDI/VDE 2617 Part 1, 2.1, 5
Accuracy of Co-ordinate Measuring Machines
Beuth-Verlag

[2] VDI/VDE 2617 Bl./Part 1, 2.1, 3
German-English Edition
Accuracy of Co-ordinate measuring machines
Beuth-Verlag

[3] VDI-Bericht 529: Koordinaten-Meßtechnik,
Verlag des Vereins Deutscher Ingenieure –
Düsseldorf, 1984

[4] CMMA Genauigkeits-Spezifikationen für
Koordinaten-Meßgeräte (1982)
Co-ordinate measuring machine manufacturers
association c/o BCM, 27 a Old Gloucester Street,
London, WC IN 3XXX

von Prüfkörpern und Koordinaten-Meßgeräten
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VDI-Verlag Düsseldorf

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of the KOBA-step step gauge
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Excerpts from our delivery programme:

- Gauge Blocks
- Gauge Block Accessories
- Angle Gauges
- Flat Gauges according to works standard specifications and client’s drawing
- Master setting pieces
- Thread Gauges
- Spline Gauges
- Plug Gauges
- Ring Gauges
- Snap Gauges

- Sphere Plate KOBA-check
- Ball Bar up to 8 m
- Ball Cube KOBA-Q3
- Optical scale KOBA-optima
- Opto-tactile standards

and our services:

- KOBA-calibration service for gauge blocks and gauges
- **DKD**-calibration as per accreditations

All orders received are subject to our terms of delivery and sale which are kept at your disposal