

**EURAMET Supplementary Comparison:**

**EURAMET.L-S28**

**High precision flatness over 300 mm**

## **Technical Protocol**

**European Association of National Metrology Institutes (EURAMET)  
comparison in accordance with the guidelines of the  
Consultative Committee of Length (CCL) and the EURAMET Guide on  
Comparisons, EURAMET Guide No. 4, Version 1.1 (12/2016)**

**Pilot laboratory:**

**Physikalisch-Technische Bundesanstalt (PTB), Germany**

**Time schedule**

**04/2020 - 06/2021**

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**Date:** 2020-01-13

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## **1 Introduction**

### **1.1 Historical background**

This supplementary comparison is based on the previous successful EURAMET project #672 “Determination of form/topography of high-quality flats”. In this EURAMET project #672 a high-quality flat made of Zerodur with a diameter of 205 mm was used as comparison artefact and the flatness measurements were evaluated on an aperture of 150 mm and 100 mm in diameter. The project was organized by PTB and the results were published in 2017 [Qua17]. Based on the experiences gained in this previous EURAMET project, now an EURAMET Supplementary Comparison using an optical flat with a diameter of 330 mm shall be executed. The participants shall measure the inner aperture of 300 mm with optical instruments only to avoid possible scratches on the surface when measured with tactile instruments. Since the comparison is intended as a high accuracy comparison, participants shall reach an expanded uncertainty of less than 15 nm ( $k=2$ ). The comparison was proposed by PTB at the EURAMET TC-L Meeting at VTT-MIKES on 16/17th of October 2017, at the meeting of CCL (Consultative Committee for Length) WG-MRA (Mutual Recognition Arrangement) in October 2017 and at the meeting of the CCL (Consultative Committee for Length) WG-N (Working Group on Dimensional Nanometrology) at BIPM on the 11th of June 2018.

### **1.2 Technical background**

The measurement and calibration of flat surfaces is important for optical systems and for reference surfaces in optics and precision engineering. Hence, many National Metrology Institutes (NMIs) offer corresponding calibrations services. Typically, optical measuring techniques like interferometry [Van08], small angle deflectometry [Ehr12] or other scanning techniques [Kre08] are applied, which may reach uncertainties down to a few nanometers. Previous investigations [Bri99, Qua17] have made it clear that a clear measurement protocol containing detailed adjustment instructions are important for the comparability of the measurements. The comparison will be done star shaped.

### **1.3 Motivation**

Within the framework of EURAMET, this is the first comparison on an optical flat with an aperture of 300 mm to be measured. The objective of this comparison is to verify the accuracy and comparability of the measurement results obtained by the participants when measuring the topography of this specific artefact using measuring instruments of high and highest accuracy. It is of great interest if the results are comparable in the range of less than 15 nm. Also, it is interesting to check, whether results obtained in the face side (vertical) and face up (horizontal) orientation of the artefact are comparable, provided that the gravitational deformation is considered, which will be calculated by Finite Element Modelling (FEM).

## 2 The standard

### 2.1 General requirements

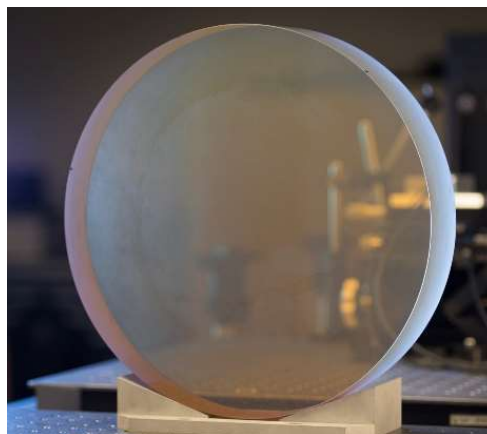
A Zerodur specimen has been selected for this comparison, see section 2.2, due to the following reasons:

- PTB uses flats made of Zerodur since many years, which show a very good long-term stability
- The glass-ceramic Zerodur has a low thermal expansion. In the range 0°C to 50 °C it has a mean thermal expansion of  $0 \pm 0.007 \times 10^{-6} \text{ K}^{-1}$ , which is two orders of magnitude better than that of fused quartz.

### 2.2 Description of the standard

The artefact is a high-quality optical flat made of Zerodur (see Figure 1), with the following characteristics:

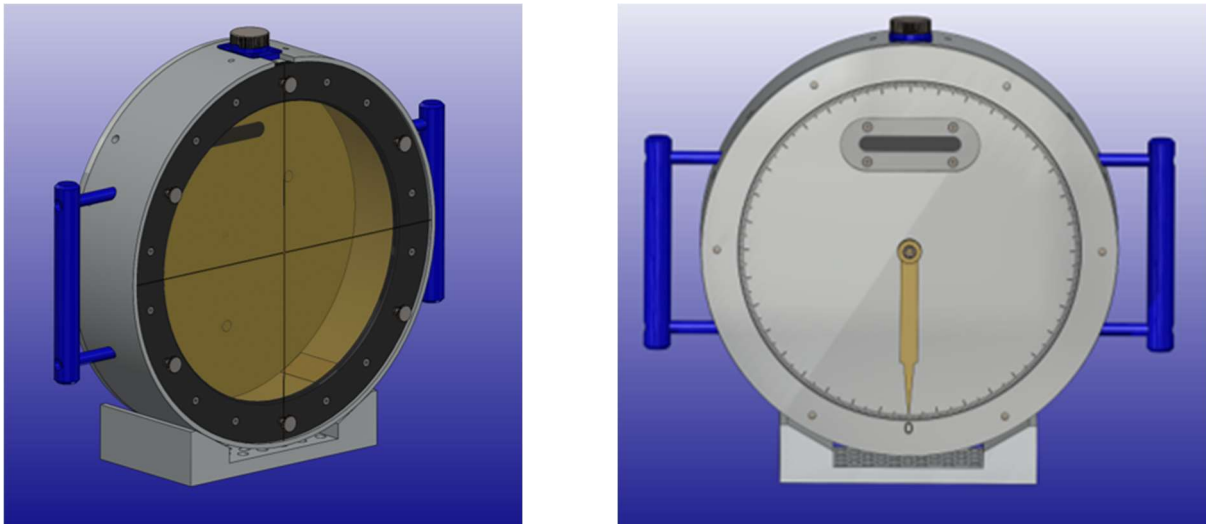
- diameter: 330 mm, aperture to be measured: 300 mm
- thickness: 71 mm
- flatness: high quality
- mass with enclosure: approx. 28 kg
- operation: face up (horizontal) and /or face side (vertical)
- further characteristics: no coating, frosted back side
- mounted in an enclosure with protection cap and transferred in a special transport box
- Cleaning of the flat surface is strictly prohibited
- the artefact is property of PTB, Braunschweig, Germany



**Figure 1.** Photo of the artefact (Zerodur)

### 2.3 Mounting

The artefact is mounted in an enclosure made of aluminium (outer diameter approx. 340 mm, height approx. 80 mm). The artefact shall not be removed (by no means) from this enclosure. The measurements shall be accomplished with the enclosure. The device is supported in the enclosure in such a way that it can be used in horizontal or vertical orientation. The enclosure ensures that the artefact rests on well-defined points. In Figure 2 a front view and a rear view of the artefact with the enclosure is shown. The optical flat is intentionally protected with a transparent cap to avoid that the enclosure will be opened and possibly scratched or damaged at customs.



**Figure 2.** Enclosure of the artefact. The optical flat is protected by a transparent cap (left). The rear side of the enclosure has a window in order to inspect whether the optical flat is twisted in the enclosure (right).

At the rear window, you can find an inspection window, in order to ensure that the optical flat has not been twisted during the transportation. Please check the inspection window, if you can see a black line. In addition, you can mount the pointer (see Fig. 2 right) at the rear side, which helps for a better alignment of the artefact in case of measurement in vertical orientation, see more detail in Section 4.2. If the optical flat is twisted during the transportation or damaged, please contact immediately the pilot. For the localization of the measured area, an adjustment mask is provided. For the interferometric measurement a mask of 300 mm is mounted on the enclosure, for the deflectometric measurements a mask of 310 mm can be used. **Please let the pilot know which mask you prefer.** The mask will be mounted onto the enclosure by the pilot. To fix the optical flat in the enclosure the knob (transport lock) on the top (see Figure 2) is to be used. **Be sure, that the transport lock is closed during transportation and that the transport lock is open during the measurement.** If the transport lock is not closed during transportation, the optical flat can rotate or even get damaged.

## 2.4 Handling

When handling the artefact with the protection cap removed, the operator should wear a face mask.

## 3 Organisation

### 3.1 Pilot Laboratory

The pilot laboratory resp. the organizer of this comparison is the Working Group 4.22 “Flatness metrology” of PTB, Braunschweig, Germany

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### 3.2 Participants

Cooperation of all participants is essential for a successful intercomparison. Participants are listed in Table 1. They are expected to:

- Provide correct and up to date contact and address details (especially delivery address) to the pilot laboratory.
- Have all resources and instrumentation ready by the scheduled time of measurement and commit to carry out measurements according to the schedule
- Ensure funds are available for onward transport of the artefact.
- On receipt of the artefact, inform the program pilot (by email) of receipt (Appendix A), any damage of the standard or of the transportation box or of any other problems or delays (Appendix B).
- On completion of measurements, re-examine the condition of the standard and notify if there is any change of the surface (Appendix B).
- Repack the artefact and make transport arrangements. Ensure that the set of documents is enclosed. Return the package to the pilot laboratory.
- Agree not to discuss any measurement results prior to distribution of the draft report (i.e. after completion of all measurements).

**Table 1.** List of participant laboratories and their contacts

Acronym	Laboratory	Country	Contact
NIM	National Institute of Metrology	China	Mr Kang Yanhui No. 18, N. 3rd Ring Rd East, Beijing, People's Republic of China email: <a href="mailto:kangyh@nim.ac.cn">kangyh@nim.ac.cn</a>
NMIJ	National Metrology Institute of Japan	Japan	Mr Yohan Kondo, Mr Youichi Bitou Tsukuba Central 3, 1-1-1 Umezono, Tsukuba, 305-8563 JAPAN email: <a href="mailto:kondou.y@aist.go.jp">kondou.y@aist.go.jp</a> email: <a href="mailto:y-bitou@aist.go.jp">y-bitou@aist.go.jp</a>
NMISA	National Metrology Institute of South Africa	South Africa	Ms Faith Hungwe CSIR Campus Building 5 Meiring Naude Road, Brummeria Pretoria 0182 email: <a href="mailto:FHungwe@nmisa.org">FHungwe@nmisa.org</a> phone: +27 12 841 4936
PTB	Physikalisch-Technische Bundesanstalt, National Metrology Institute	Germany	Mr Gerd Ehret PTB, Bundesallee 100, 38116 Braunschweig, email: <a href="mailto:gerd.ehret@ptb.de">gerd.ehret@ptb.de</a>
VNIIMS	Russian Research Institute for Metrological Service	Russia	Ms Ekaterina Milovanova 46, Ozernaya st., Moscow 119361, Russia email: <a href="mailto:milovanova@vniims.ru">milovanova@vniims.ru</a> or Mr Valeriy Lyssenko, <a href="mailto:lysenko@vniims.ru">lysenko@vniims.ru</a> or Mr Denis Novikov, <a href="mailto:dnovikov@vniims.ru">dnovikov@vniims.ru</a> phone: +7 (495) 781-86-53
XFEL <sup>1</sup>	European XFEL GmbH	Germany	Mr Maurizio Vannoni European XFEL GmbH Holzkoppel 4 22869 Schenefeld, Germany email: <a href="mailto:maurizio.vannoni@xfel.eu">maurizio.vannoni@xfel.eu</a> phone: +49 40 8998-5456

<sup>1</sup> This external partner participates unofficially.

### 3.3 Time schedule

(Remark: The time schedule will be coordinated with the participants.)

**Table 2.** Schedule of the comparison

Laboratory	Starting date of measurement

### 3.4 Transportation

The transport box will be packed in an additional carton and be sent to the participant by a parcel service at the expense of the pilot. The time of sending the device is coordinated between pilot and the participant. When the parcel is sent, the pilot informs the participant by email. When it reaches the participant, the participant checks the integrity of the parcel and informs the pilot by email about the delivery.

### 3.5 Unpacking and preparation for measurement

The participant takes the transport box out of the outer carton and checks possible damages of the transport box. In case of damages, the pilot is contacted.



**Figure 3.** Photo of a typical transport box

Then, the transport box is brought into the measurement laboratory and kept closed in this room for 48 hours in order to achieve temperature equilibrium and to avoid possible water condensation. After this time, the transport box can be opened. In the upper right part of the box, the environmental sensor is mounted. It shall not be removed.

The enclosure is put on a table with the cap upside and the transport lock (see **Figure 7**) is unfastened by pulling and turning the knob by 90°. Please take care to unfasten the transport lock to have the flat in a relaxed state when the measurements are performed.

Then, the screws fixing the cap are unscrewed and the cap is removed. Please remember to wear a face mask to avoid contamination from breathing.

Please check the integrity of the flat visually (in case of a negative result, please contact the pilot) and check inspection window. If you can see the black line, in order to be sure that the flat is not twisted inside the enclosure.

### 3.6 Repacking and return transport

The participant places the flat with the enclosure on a table, removes the mask holder and places the cap on the enclosure. Then the cap is fixed with the screws. Close the transport lock screw. All components are inserted in the transport box. Please send an email to the pilot announcing the transport.

### 3.7 Financial aspects, insurance

There is no funding for this project. The costs for the measurements, return transportation, transportation insurance, eventual customs formalities as well as for any damages not covered by transportation insurance are at charge of each participant.

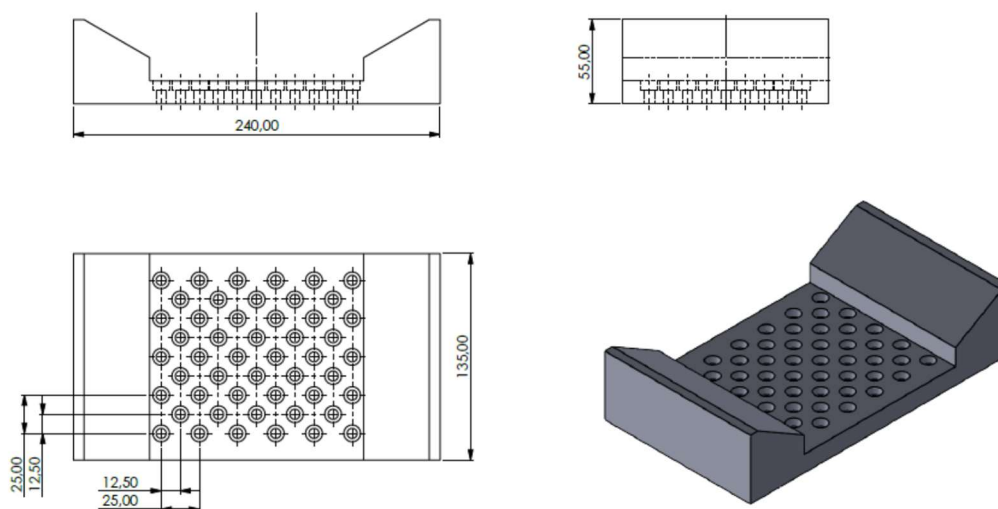
## 4 Measuring instructions

### 4.1 Measurement method

Different optical measurement methods like interferometric and deflectometric methods exist to determine the flatness of this artefact. The optical measurement method is not prescribed. It should have – as described above – the possibility to obtain an expanded uncertainty of less than 15nm ( $k=2$ ). Measurements in vertical as well as horizontal orientation (or both) of the artefact are welcome.

### 4.2 Measuring the artefact in vertical orientation

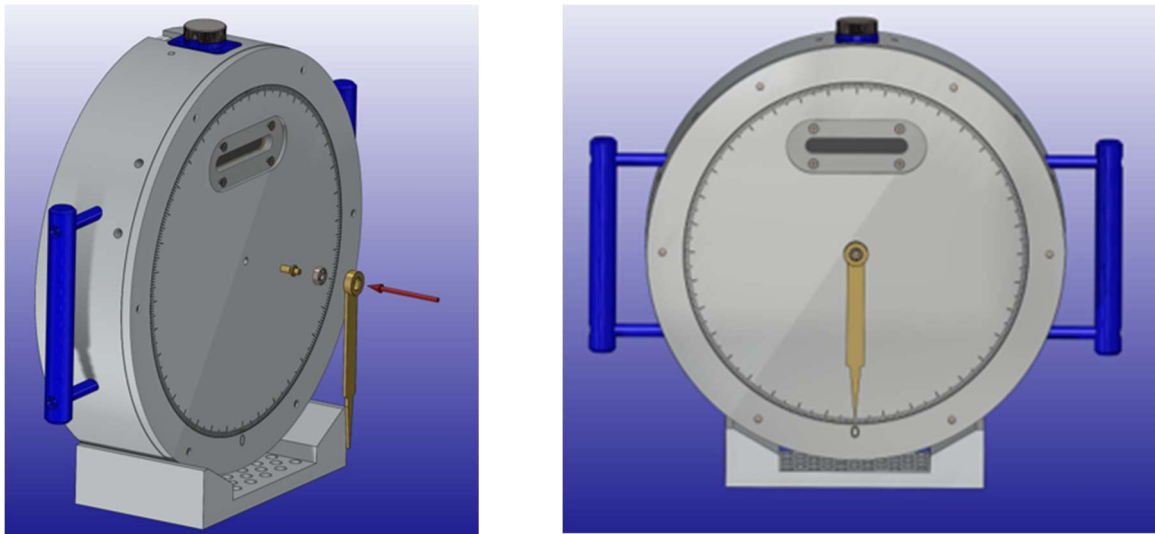
In vertical orientation, the flat is standing on two cork strips fixed inside the enclosure. The enclosure can rest in a V-groove, for example. The pilot provides a V-groove (see **Figure 4**) which may be used by any partner. Put the artefact in a V-groove in front of the interferometer. The transport lock knob shall be at the 'up' position.



**Figure 4.** This V-groove will be provided by the pilot and can be used for the measurement in vertical orientation. The provided V-groove can be mounted e.g. on the optical table.



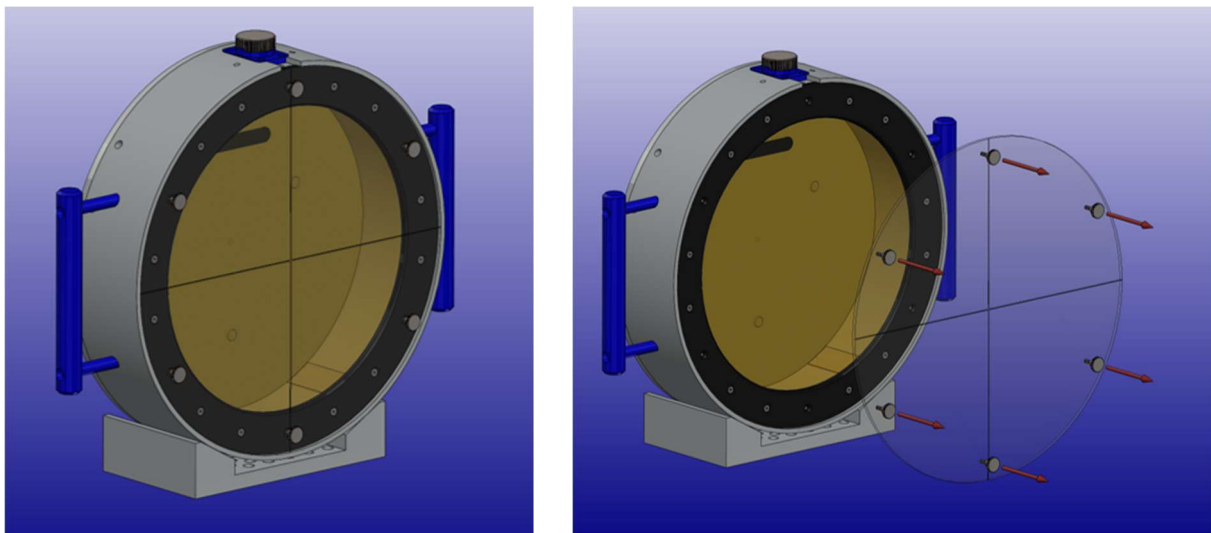
For a fine orientation of the artefact a mechanical pointer on the rear side shall be used. you find this pointer in the transportation box. Mount the pointer as it is shown in Figure 5.



**Figure 5.** Mount the pointer at the rear side of the enclosure (left) and place the enclosure in such a way into the V-groove, so that the pointer points to the zero. Take a photo for documentation.

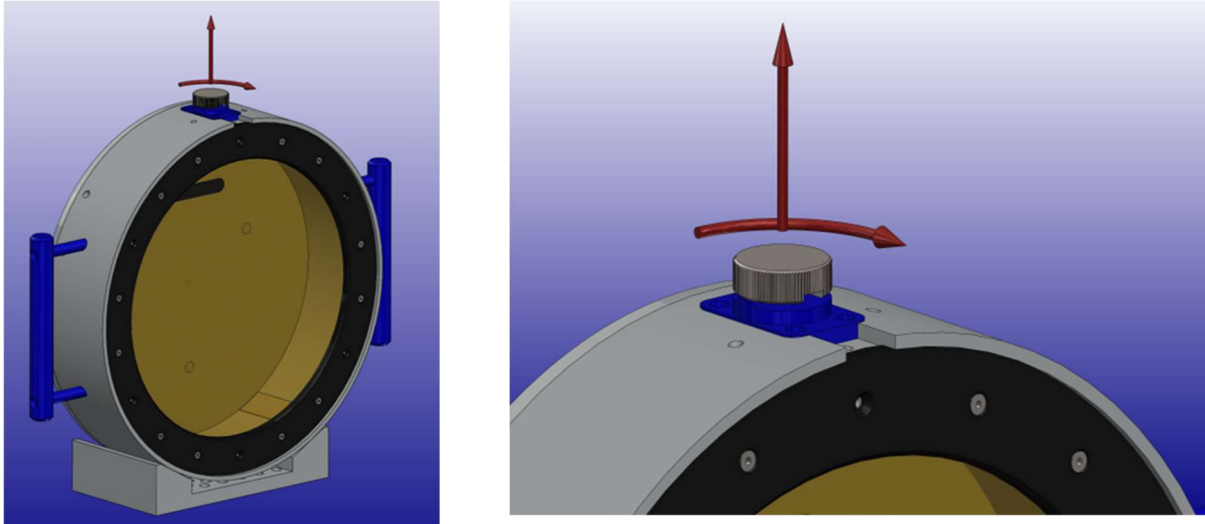
Then orientate the artefact such that the pointer points to the zero position. Take a photo for documentation. Have also a look to the inspection window to be sure, that the optical flat is not twisted in the enclosure. Take a photo of the inspection window.

Remove the transparent protection cap by loosening the 6 screws, see **Figure 6**.



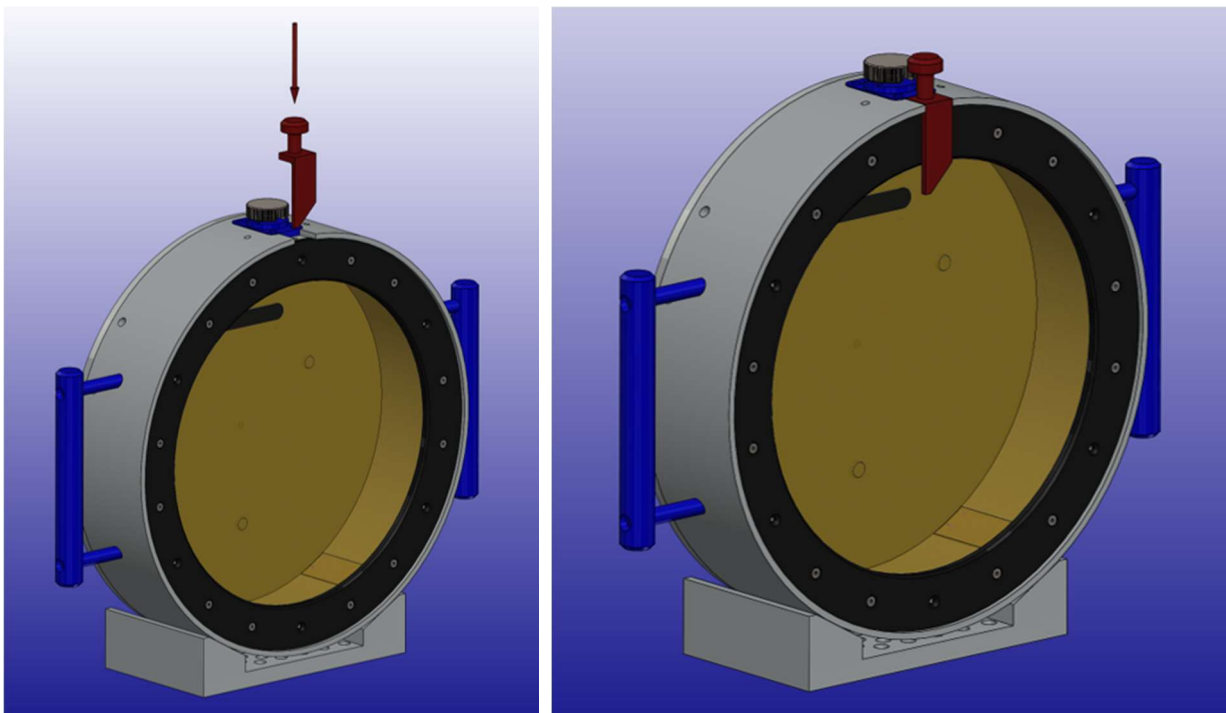
**Figure 6.** Remove the transparent protection cap by loosening the 6 screws (no tools required)

Open the transport lock by pulling and rotating the knob by 90°(see **Figure 7**) . Then wait for at least 48 hours so that the artefact can relax and can achieve temperature equilibrium.

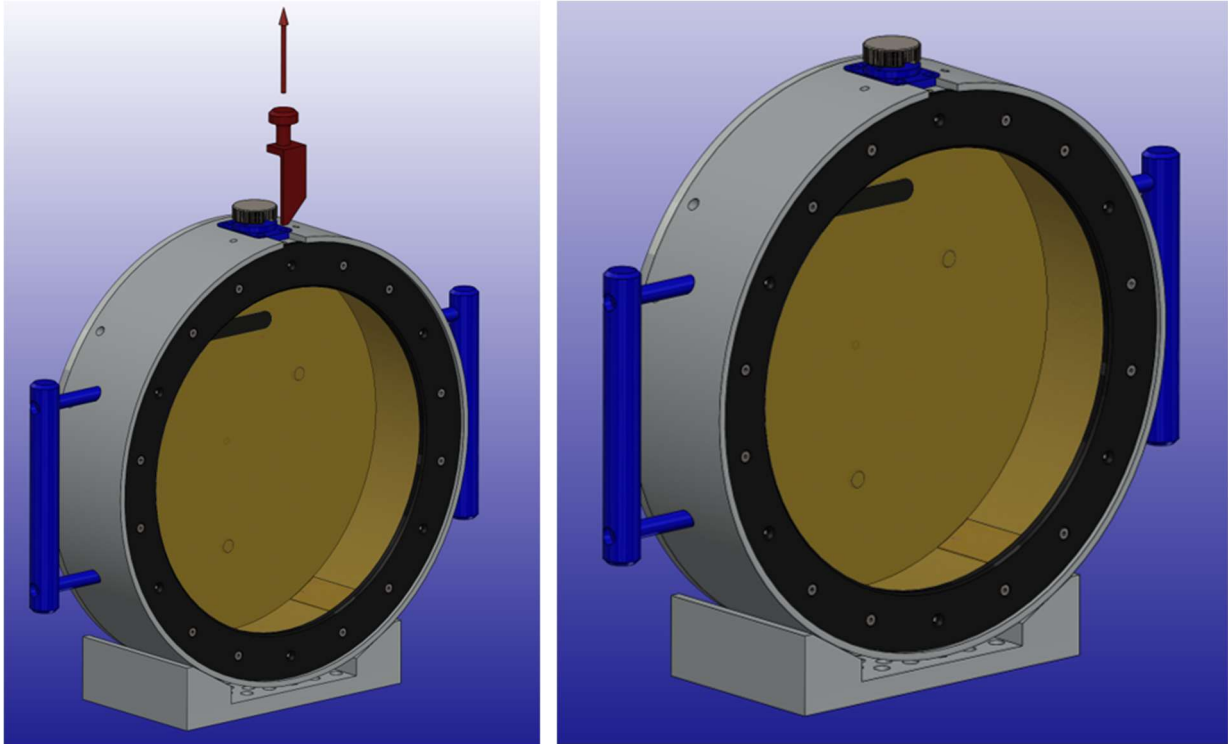


**Figure 7.** Open the transport lock by pulling and rotating the knob by 90°.

Insert the orientation tool and take an image with your measurement system, in order that the mask (see **Figure 8**) is visible. This is important in order to compare later the results of the partners. The use of this orientation tool uniquely identifies the position and orientation of the surface in the results. Thereafter, gently remove the orientation tool and, if necessary, perform a fine-adjustment of the tilt. Then, the real measurement is performed. Be careful, to process the data from the adjustment measurement exactly in the same way as those from the real measurement. No change or shift of the coordinate axes is allowed between the adjustment and final measurement.

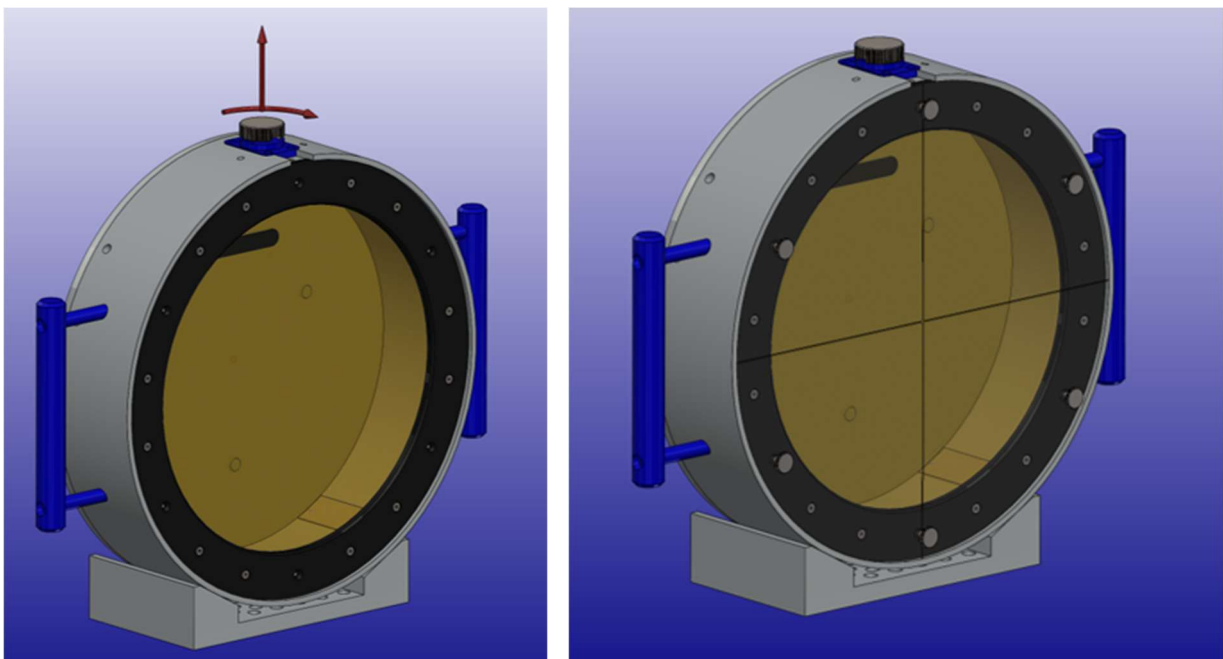


**Figure 8.** Insert the orientation tool and take an image with your measurement system. This is important in order to compare the results of the partners.



**Figure 9.** Remove the orientation tool. The artefact is ready for measurement.

Close the transport lock after the measurement and mount the transparent cap onto the enclosure. Afterwards the artefact can be placed into the transportation box.

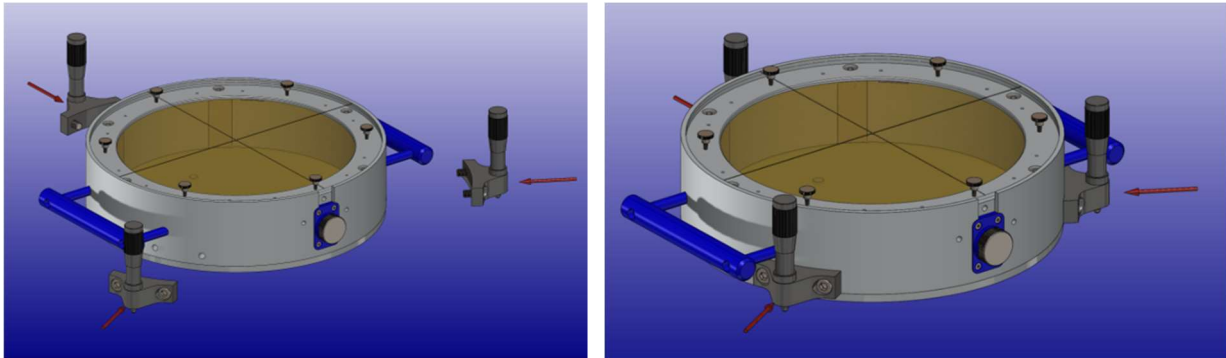


**Figure 10.** After the measurement: Close the transport lock (**very important!**). Mount the transparent cap onto the enclosure.

### 4.3 Measuring the artefact in horizontal orientation

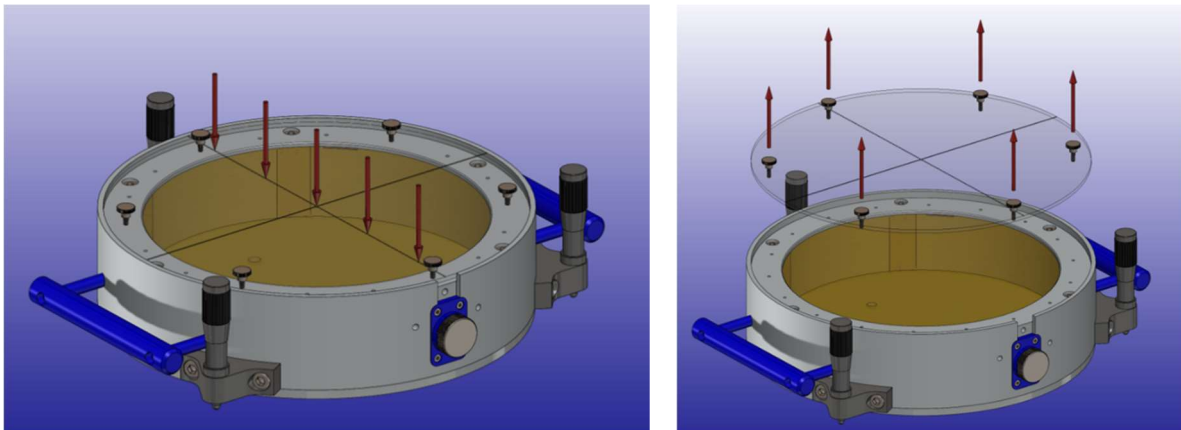
In the horizontal orientation, the flat lies on three support pads (made from cork) fixed in the enclosure. The position of these pads was optimized by FEM calculations to result in a low deformation of the specimen.

After removing the artefact from the transportation box, mount the 3 micrometer screws at the enclosure (see **Figure 11**) The 3 micrometer screws can be used for the alignment of the artefact in the measurement system.



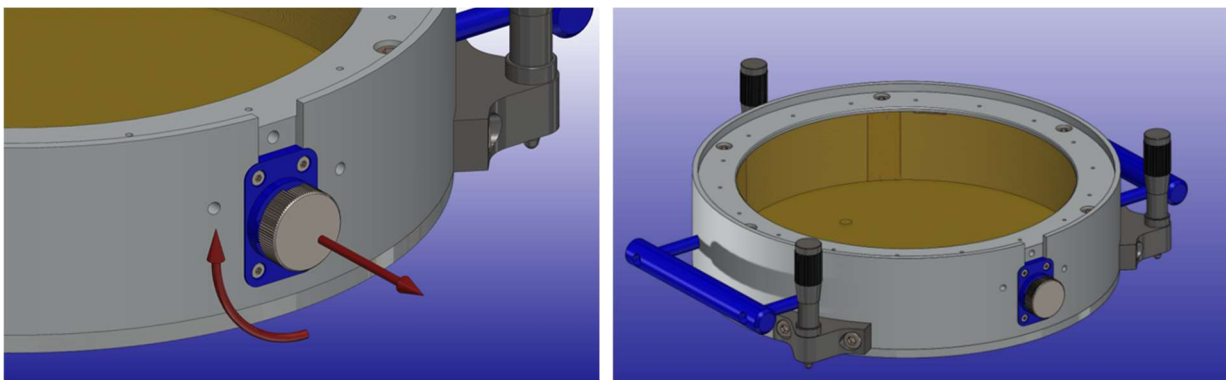
**Figure 11.** Mount the 3 micrometre screws at the enclosure of the optical flat.

Use the line of the transparent cap to align the artefact in the measurement system (see **Figure 12**) . Afterwards the cap can be removed.



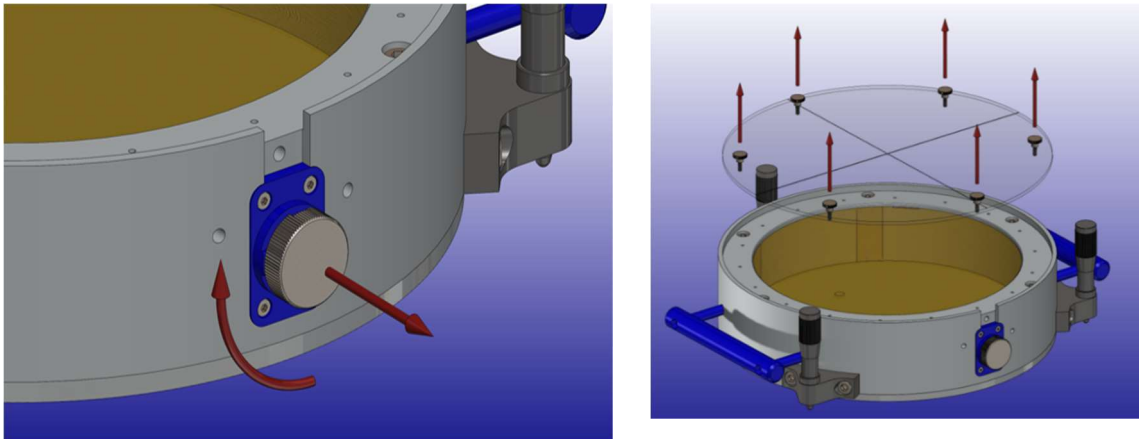
**Figure 12.** Use the line of the transparent cap to align the artefact in the measurement system. Afterwards the cap can be removed.

Open the transport lock by pulling and rotating the knob by 90°(see **Figure 13**) . Wait at least 48 hours that the artefact can relax and is temperature stabilized.



**Figure 13.** Open the transport lock by pulling and rotating the knob by 90°.

When the measurements are completed close the transport lock (see **Figure 14**). Mount the transparent cap onto the enclosure and put it back in the transport box.



**Figure 14.** After the measurement: Close the transport lock (**very important!**). Mount the transparent cap onto the enclosure.

#### 4.4 Reporting results

The data of the adjustment measurement, real measurement and the photo of the set-up can be stored in the transport box on a storage medium or sent by email together with a report of the measurement. The file format can be CODE V or Zygo.dat or an ASCII text file with a description of the file format.

#### 4.5 Uncertainty of the measurement

With the report of measurement, an uncertainty budget according to the “Guide to the Expression of Uncertainty in Measurement” (JCGM 100:2008) with corresponding coverage factor, and estimation of the lateral resolution of the instrument and information about the distortion of the imaging system (in case of interferometers) shall be delivered. If possible, no filtering should be applied to the data. If filtering is applied, it shall be reported.

#### 4.6 Measurement report

The report submitted by every participant should include the following information:

- Date of calibration
- Laboratory temperature
- Description of the calibration method (s)
- Mounting of the enclosure
- Description of the measuring equipment including a photo of the setup
- Final measurement results
- The detailed measurement uncertainty budget in the form of Table 3:

**Table 3.** Measurement uncertainty budget

Input quantity	Probability distribution	Value	Standard measurement uncertainty	Sensitivity coefficient	Uncertainty contribution
...	...				
...	...				
...	...				
Combined standard measurement uncertainty ( $k=1$ ):					
Expanded measurement uncertainty with 95% coverage interval:					

All results should be supplied in electronic form and should be written in English.

## 5 Comparison, analysis of results, final report

The comparison of the results, the analysis of the data and a Draft A Report will be prepared by the pilot. From the data of the participants, the pilot generates height data on a regular grid, corrected for the delivered distortion functions. The lateral resolution is chosen as high as possible. From the data of all participants, weighted with the inverse of the squares of the assigned measurement uncertainties, a mean topography with its measurement uncertainty is calculated and the deviations from this mean topography are calculated and reported, as well of the peak to valley and root mean square values are evaluated. If this procedure turns out to be not suitable, other data comparison procedures may be applied.

This report will include a summary of the measurement techniques employed by each participating laboratory, together with their tabulated measurement values with uncertainties. This report will be circulated to all participants for comment.

The revised version of this report (Draft B report), following these comments, will be approved by all the participants before being released to the appropriate technical committee and EUROMET Secretary for their approval.

## 6 References

[Qua17] S. Quabis, M. Schulz, G. Ehret et al.: Intercomparison of flatness measurements of an optical flat at apertures of up to 150 mm in diameter, *Metrologia* Vol 54, pp. 85-93 (2017)

[Van08] M. Vannoni, G. Molesini: Three-flat test with plates in horizontal posture, *Appl. Opt.* 47 2133–45 (2008)

[Ehr12] G. Ehret G, M. Schulz, M. Stavridis and C. Elster, Deflectometric systems for absolute flatness measurements at PTB, *Meas. Sci. Technol.* 23 094007 (2012)

[Kre08] P. Křen: A simple interferometric method for determining the flatness of large optical flats with 1 nm repeatability, *Meas. Sci. Technol.* 19 107001 (2008)

[Bri99] L. D. Briers: Interferometric optical testing: an inter-laboratory comparison *J. Opt. A: Pure Appl. Opt.* 1 1–14, (1999)

**Appendix A – Reception of the standard**

To:	Physikalisch-Technische Bundesanstalt WG 4.22 Flatness Metrology Bundesallee 100 38116 Braunschweig Germany Fax: +49 531-592-69 4220	e-mail: gerd.ehret@ptb.de
From:	NMI: .....	Name: .....
	Signature: .....	Date: .....

We confirm having received the optical flats for the EURAMET.L- S28 comparison on the date given above.

After visual inspection:

- There are no apparent damages; their precise state will be reported in the form provided in Annex B once inspected in the laboratory.
- We have detected severe damages putting the measurement results at risk. Please indicate the damages, specifying every detail and, if possible, include photos. If necessary, use additional sheets to report it.
- Shock watch sensor (attached to the aluminium transportation box) was activated

**Appendix B – Conditions of Specimen Face**

To:	Physikalisch-Technische Bundesanstalt WG 4.22 Flatness Metrology Bundesallee 100 38116 Braunschweig Germany Fax: +49 531-592-69 4220	e-mail: <a href="mailto:gerd.ehret@ptb.de">gerd.ehret@ptb.de</a>
From:	NMI: ..... Name: ..... Signature: ..... Date: .....	

We made a detailed inspection of the specimen face of the optical flat. Surface faults (scratches, indentations, corrosion, etc.) are marked and described here (if necessary, use additional sheets / photos):

Flat with a diameter of 330 mm

