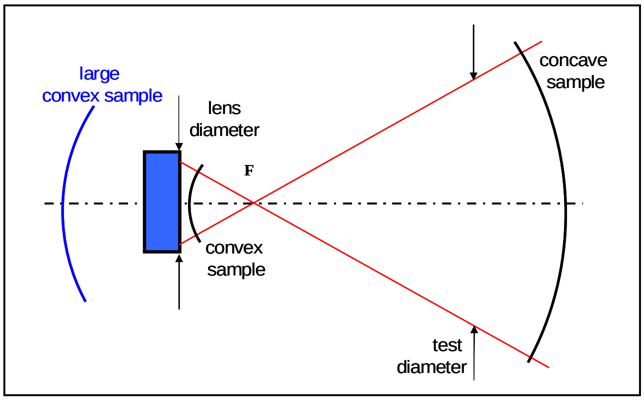
# Application Report: Lateral Stitching of Large Spheres

## General

This document describes a measurement procedure for determining the surface topography of large spherical samples which can be measured in sub-apertures only.

## 1 Measurement Task

An interferometric measurement of spherical surfaces is quite easy in general. But it becomes difficult when the test aperture and/or the radius of curvature become very large. Large radii are a problem especially in cases of convex samples, because they require an appropriate test lens with corresponding working distance (focal length). For single-aperture testing also the test lens diameter has always to be larger than the sample test diameter.

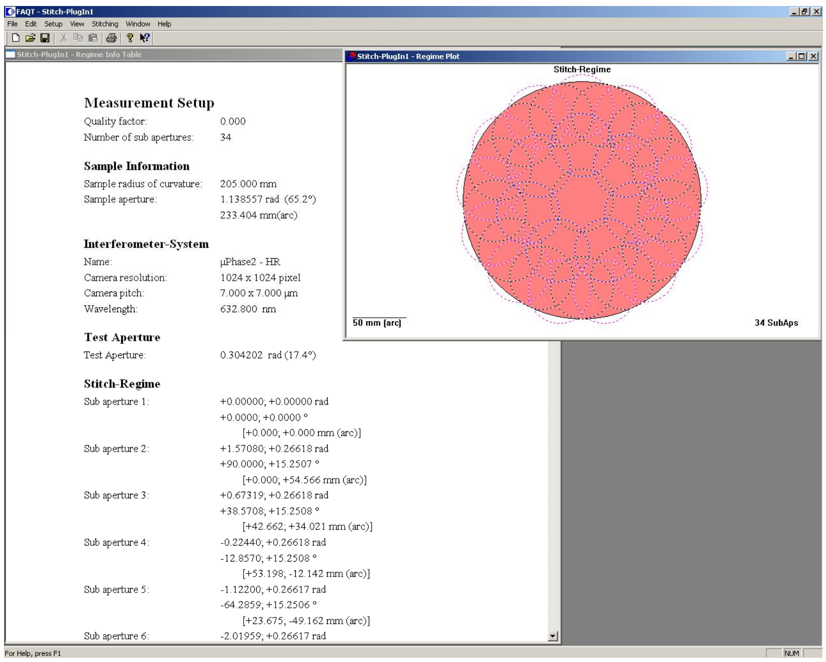



Concave samples are measured behind the focal point F of the test lens and therefore only the numerical aperture of the test lens has to fit. A short focal length reduces the working distance. The lens diameter can be much smaller than the test diameter.

Large test lenses especially with large working distance (focal length) are expensive and often not available. When you have to test large convex sample nonetheless, the only possibility for interferometric testing is a measurement of individual sub-apertures and to connect (stitch) them together. Stitching can also be useful for "normal" sized samples when objectives with very high aperture (e.g. >90°) are required.

## 2 Stitch Regime

The basic algorithm of a lateral sub-aperture stitching described in this report bases on overlaps between neighbored sub-apertures. In order to measure the complete sample surface you have to ensure that all parts of the sample are at least measured in one of the sub-aperture measurements.



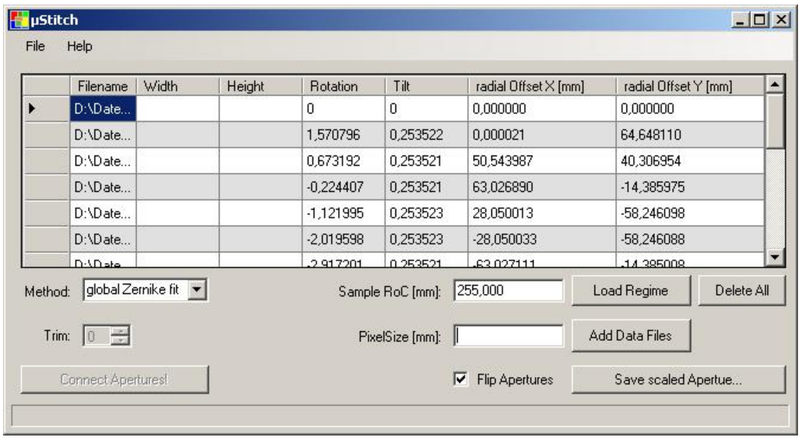

FISBA developed a plug-in module for its FAQT tool, allowing the user to specify the sample (radius and test diameter) and defining a selection of available test setups (interferometer + objective) to be analyzed. Then the tool determines for each setup the required number of measurements and determines a quality factor for each setup.

Main parameter for the quality factor is the amount of required measurements; the less the better. Finally the best Setup is selected and displayed as graphical view as well as a table. This table contains the parameter of the individual sub-apertures in local shift and rotation coordinates. The calculated stitch regime can be saved as ASCII file.

Using this stitch regime ensures that all parts of the sample are measured. The listed coordinates simplify the adjusting of the individual test positions and could also be used for automation purposes.

## 3 Measurement Regime

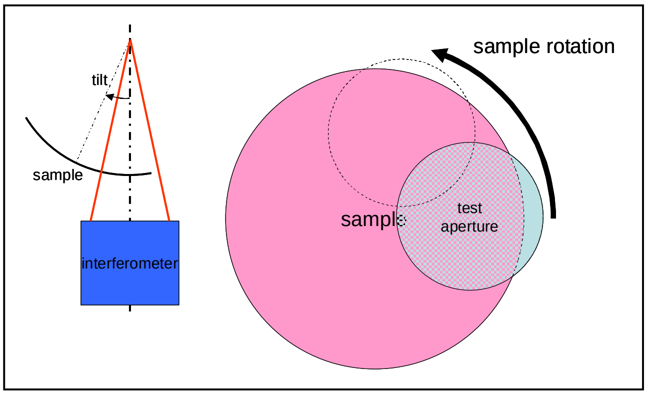
The individual sub-aperture measurements are connected in another program developed by FISBA. It allows you to load stitch regimes generated by the FAQT tool and to import measurement data exported in µShape™ binary (.dat) format. If the actual measurement positions differ from the pre-defined ones, the stitch regime can be adapted manually to the actual measurement regime.

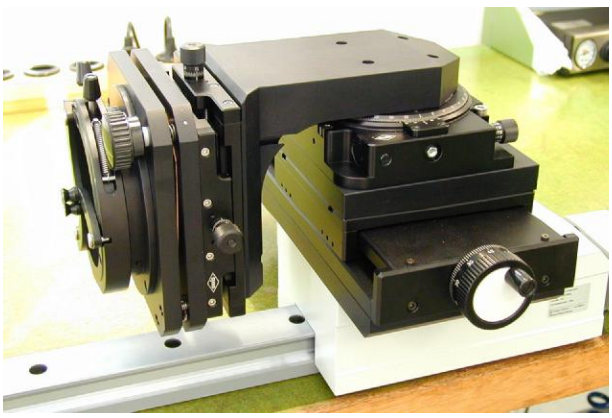


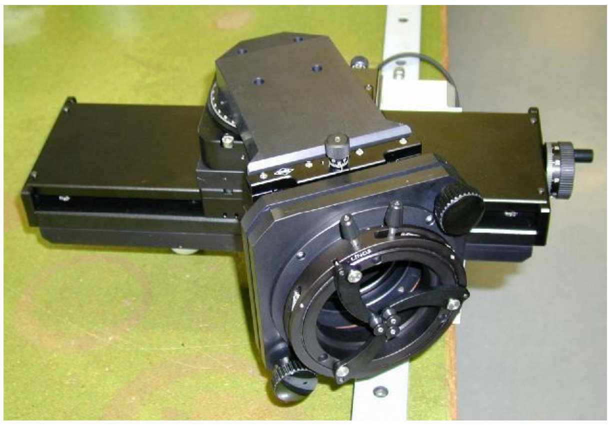

The measurements haven't to be done in the order of the stitch regime but it simplifies the assignment of regime data and measurement files.

Further important is how the measurement setup is realized. For plan setups the most common realization will be a Cartesian positioning device in x-y-direction. For spherical setups a device with two rotation elements will be more adequate minimizing the adjustment effort. Instead of three translation and two tilts the positioning can be done by only two rotations (ideal case).

Which positioning method is used does not matter in principal but it has to be considered during the stitch analysis.





The pictures above show an example of a special holder which could be easily adapted for these rotation measurements by inserting an additional rotation table behind the 3-finger-clamp.

# 4 Stitch Analysis

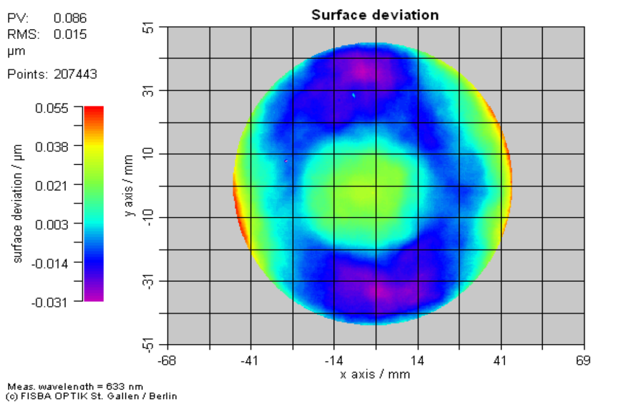
The stitching is done by a least squares fit based on Zernike polynomials. Therefore all sub-aperture measurements are described by Zernike polynomials up to 10th order. As result of the stitching algorithm you get a set of Zernike coefficients for the global aperture. Caused in the usage of a polynomial description for the individual apertures the rotation of the individual sub-aperture measurements can be easily considered and retracted. Also the global result can be easily compared with the individual measurements allowing to determine a quality value. The rms value of the difference between the global and sub-aperture results is calculated and displayed as fit quality.

Finally the result is re-transformed into a data map of the size of an individual sub-aperture measurement and saved as µShape™ binary file. This file can be imported into µShape™. With help of the Add-on Module *Sample Normal Data* the global aperture can be further analyzed as if it were measured in a single measurement.

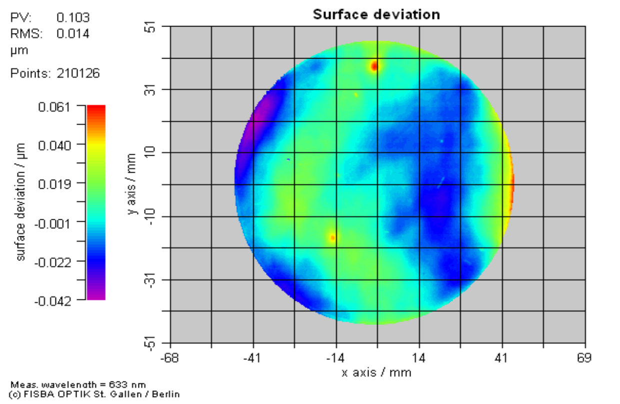
# 5 Example

The following example shows the stitching of a sphere with a radius of curvature of 205 mm and a diameter of 221 mm. As test lens a 4" f/3.3 objective was used. Each measurement captures an angle of 0.29 radian (~16°) corresponding with a test diameter of about 60mm at the sample surface. The corresponding stitch regime is displayed in chapter 2. It consists of three rings; a central aperture and two additional rings with a radius of 64mm resp. 98mm. In total 1+7+10=18 measurements were taken.

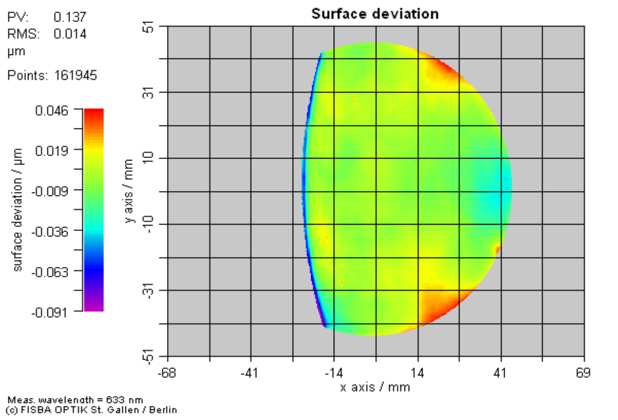
The following pictures show exemplarily four sub-aperture measurements taken from the different analysis rings.



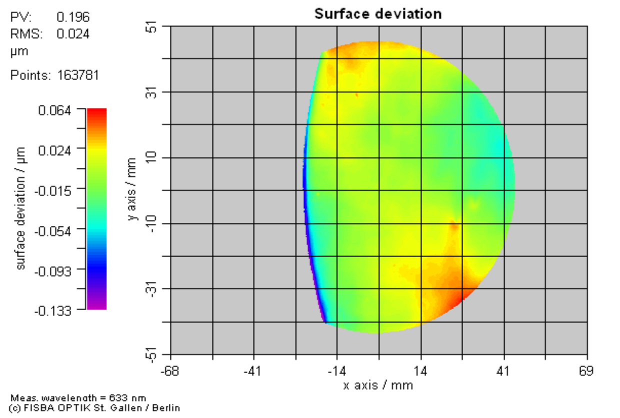

central aperture (r=0mm; ϕ=0°)




R1_pos1 (r=64mm; ϕ=90°)




R2_pos2 (r=98mm; ϕ=90°)

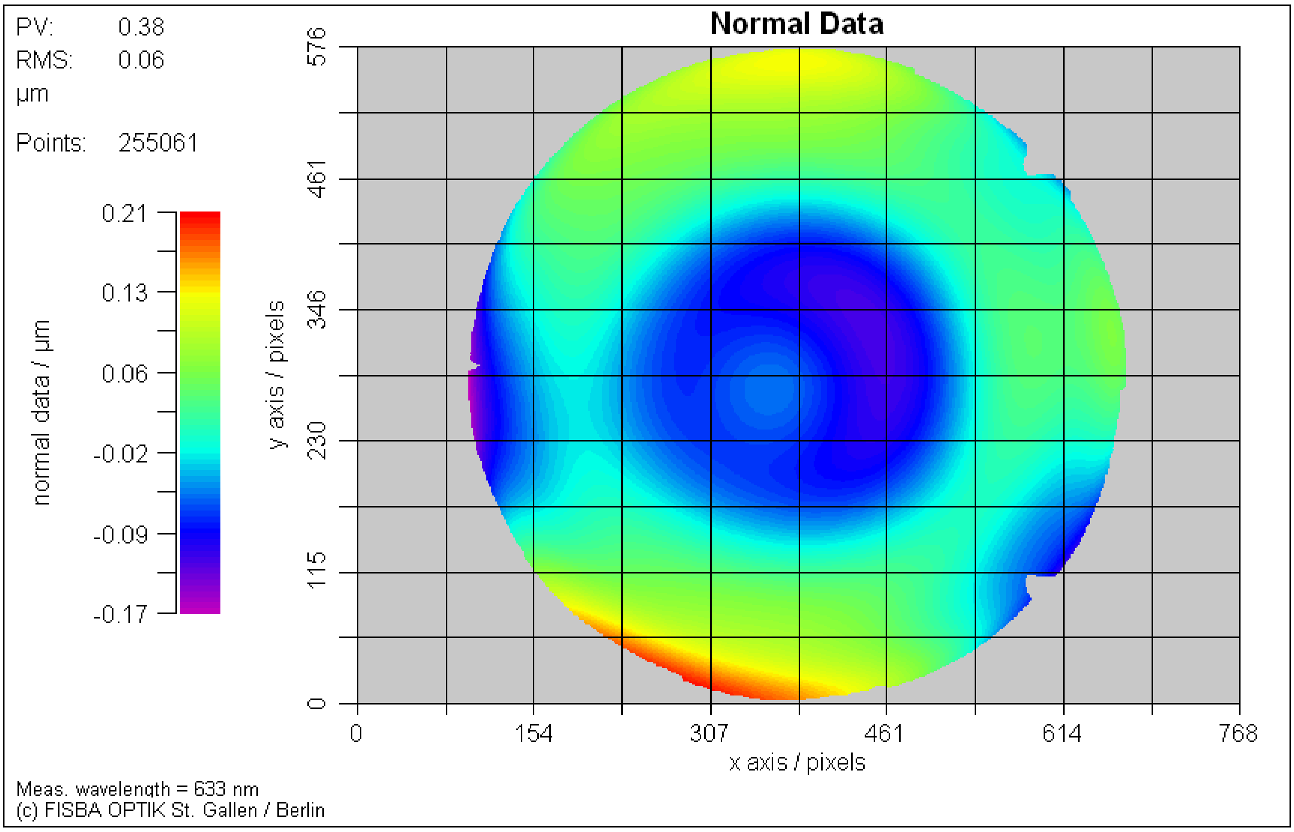



R2_pos2 (r=98mm; ϕ=126°)

The measurement top left shows the central aperture. The top measurement of the first ring is shown in the top right. The two measurements at the bottom show two neighboring measurements (90° and 126°) at the second (outer) ring.

As you can see in the last two measurements seem to have the same aperture shape although they differ by a rotation of ~36°. This is caused by the test setup described in chapter 3. The outer ring measurements are not circular anymore because of the sample edge. Caused by the interferometer setup the measurements are displayed inverted (left-right and top-bottom are switched). That is the reason why the sample edge appears on the left side instead of the right. This happens for all measurements and has to be considered in the analysis, but the effect is conspicuous only in the outer ring measurements.

From all 18 measurements the following global aperture is determined:




At the outer rim you can see the holder at +/-60° and 180°. This data map can be further analyzed (e.g. slope, ISO etc.) inside µShape$^{TM}$ as if the sample would be measured in a single measurement completely.

# 6 Outlook

Although the stitching algorithm presented here was primarily developed for testing large spheres, it is also applicable for other test setups.

For more convenience other regimes can be implemented. For stitching large flats possibly Cartesian translations instead of rotation will be more convenient.

If you need more information don't hesitate to contact us at software@fisba.de.