Unrolled 3D confocal measurements of turning parts

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Unrolled 3D Confocal Measurements of Turning Parts

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ABSTRACT

Three-dimensional measurement of cylindrical surfaces is today accomplished with the use of an optical measurement system and dedicated rotational stages. Cylindrical measurements are commonly taken field by field by rotating the sample and stitching all the fields. The main drawback of optical instruments is the fact that the field distortion, and residual flatness error are slope dependant, and only corrected for flat samples, which is not the case due to the cylindrical shape. We propose the use of a rotational stage with the combination of a slit-confocal imaging system capable of acquiring unrolled confocal images with a line-scan approach while the sample is rotated at constant speed. Three-dimensional measurements of cylindrical surfaces are taken minimizing the errors appearing on the field stitching technique.

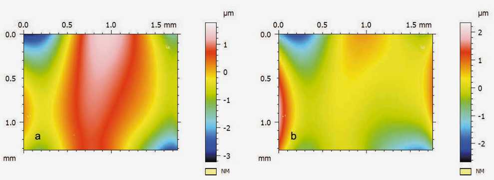
INTRODUCTION

Confocal microscopes are widely used for areal measurements thanks to its good height resolution and the capability to measure high local slopes [1]. For measuring cylindrical surfaces, the sample has to be fixed on a rotational stage, and several topographies have to be acquired at different angles. The amount of individual topographies depends on the sample diameter and the field of view.

The main interest on cylindrical parts are the roughness, the shape deviation and the lead and twist analysis. This imposes the need to remove from the measurement the nominal cylinder that appears when stitching all the individual data.

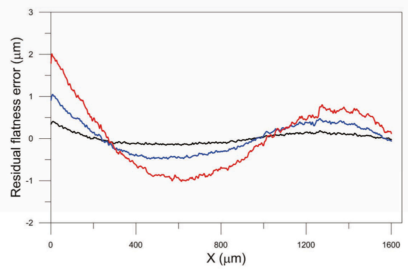
Independently of the fitting approach there are low frequency errors on the residual flatness due to the confocal calibration correction [2].

GLASS ROD



Residual flatness best-fit radius (Ø10.4mm) — *Residual flatness nominal diameter fitting (Ø10.0mm)*

Confocal microscopes are calibrated with a reference mirror perpendicular to the optical axis [3]. This correction is not accurate when having tilted surfaces.



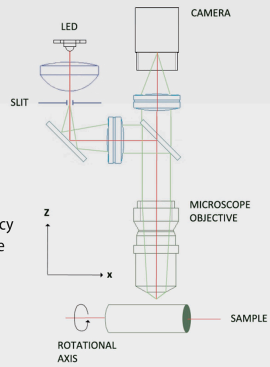
Residual flatness error with a 10X confocal objective measuring a tilted flat mirror at 1 (black), 5 (blue), and 10 (red) degrees.

We propose a new measurement method based on the fact that cylindrical samples do not show high slopes in the direction of its revolution axis, making the residual flatness error to be minimal in that direction.

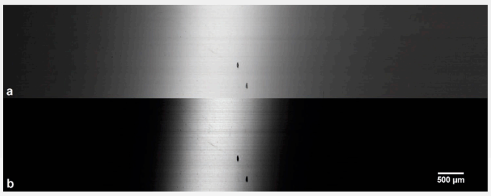
METHOD

An unrolled confocal image of the cylinder surface is built by rotating the sample and calculating the confocal intensity at the centre of the slit. A set of confocal images are obtained at different heights of the sample and used to calculate an unrolled areal measurement of the cylinder. The benefits of this new approach are:

- Measurement time is shorter
- Nature of the unrolled data is 2.5D
- No need to remove cylindrical shape as it is naturally removed by the acquisition method
- Minimized flatness error
- Preservation of the low frequency components achieving trustable waviness results
- Uniform sampling due to constant perpendicular projection of the sample with the optical axis



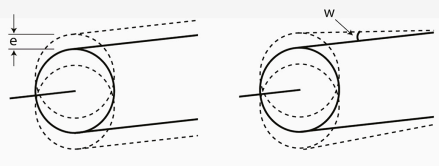
Next, we compared the performance of two different confocal approaches (intensity recording and gradient algorithm) by obtaining images of a glass rod with a 10X 0.3NA objective on the same axial position. Only a certain part of the image is on focus due to the run-out error of the rotation.



Confocal approaches: (a) intensity recording vs (b) gradient algorithm. The latter produces higher contrast images.

ERROR INFLUENCES

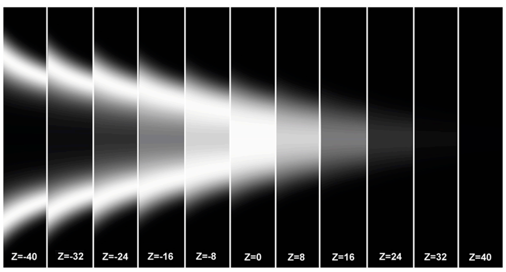
The rotational axis and the clamping mechanism will introduce to the final measurements circularity, cylindricity and concentricity errors that should be characterized and removed. The two major error sources are the total run-out and the wobble.



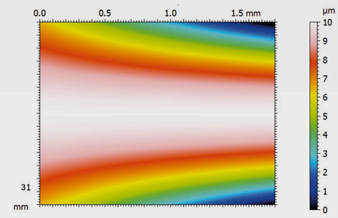
Run-out — *Wobble*

These two errors manifest on the topography as low frequency components that correspond to the periodicity of a full turn of the surface. By identifying such form errors, it is possible to predict their amplitude and isolate the components on the topography by subtracting them from the raw data:

$$\Delta z = (e + \tan(w)\cdot X)(1 - \cos(\alpha))$$



Series of 11 confocal images of a glass rod with a 10X 0,3NA objective, run-out error e of 10 µm and wobble w of 1°

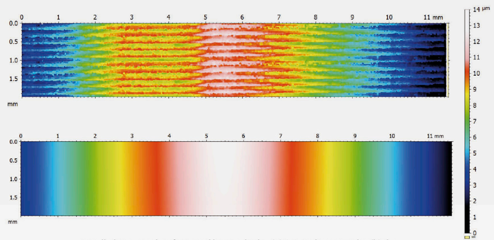


The residual error of the 3D Topography

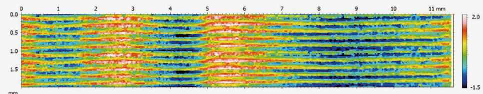
RESULTS

To proof the concept, we used a 10X 0.3NA microscope objective to acquire the unrolled confocal images, and optimum Z increment steps of 2.0 µm to get a series of images of a brass turned part of 4.0 mm in diameter.

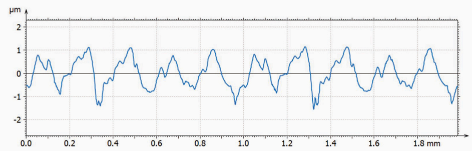
The unrolled topography shows the helix shape clearly visible, as well as the low frequency components coming from the run-out of the rotational stage.



Unrolled topography of a turned brass cylinder. (a) Original topography, (b) the best-fit from run-out and wobble errors



Unrolled topography of a turned brass cylinder of 4 mm diameter after removing the best-fit error



Profile cut of the previous image in the X direction.

CONCLUSIONS

We have discussed the residual flatness error appearing in imaging confocal microscopes when measuring cylindrical parts. We have reviewed the stitching approaches to measure turned parts and how the residual error leaves low frequency components that do not correspond to the surface under inspection. To overcome this problems we have shown a new optical method that uses a slit projection and a rotational axis to acquire a series of unrolled confocal images and recover the 2.5D surface topography. The advantages are: no required stitching, reduced flatness error, and increased speed to minimize overall measurement time. We have also analyzed the source of the errors of this new acquisition approach and proposed a mathematical correction method.

References

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[2] Sensofar Tech App. Note. "Flatness error on Imaging Confocal Microscopes," (2009), http://www.sensofar.com/references/FlatnessError.pdf (11 April 2017).

[3] Claudiu L. Giusca, Richard K. Leach. "Calibration of the scales of areal surface topography-measuring instruments: part 1. Measurement noise and residual flatness," Measurement Science and Technology (2012).