Title: Optical and tactile metrology for absolute form characterisation

Abstract

Optical surfaces of highest quality are needed in various high-tech applications, e.g. in optical and semiconductor industry, precision engineering, synchrotron facilities etc. There is a strong demand for traceable and absolute asphere and freeform metrology.

Surface measurements can be divided into imaging and scanning methods. Imaging methods, such as optical interferometry are non-destructive and potentially very accurate. Scanning methods, such as tactile CMMs are universal, have good lateral resolution, but are slower. Improvements in manufacturing capability, particularly of high specification components, cannot currently be fully utilised due to limitations in the measurement of flatness, sphericity and multidimensional form. The objective of the proposed research should be to significantly improve these measurements.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, sections on "*Metrology R&D for applied and fundamental metrology"* related to *Industry* on page 13 and *"Innovative set-ups for new industrial and societal needs" on p38-39*.

Keywords

Optical form measurement, coordinate metrology, surface interferometry, aspheres, freeform, synchrotrons, photolithography, multi-sensor methods, deflectometry, virtual instruments

Background to the Metrological Challenges

Whilst the mass production of optical components is mainly undertaken outside the EU, European companies have a leading position in high-quality optical production. Optical surfaces of highest quality are needed in various high-tech applications, e.g. in optical and semiconductor industry, precision engineering, synchrotron facilities, communications technologies, astronomy and space industry etc.

Manufacturing of optical surfaces has improved steadily and nowadays manufacturing techniques like magneto-rheological or ion beam figuring can remove material from the surface at the nanometre level. This enhanced capability cannot however be used for improved applications since the measurement uncertainty for surface topography characterization is currently much higher. Accurate, traceable and absolute asphere and freeform metrology is therefore required for manufacture of optical surfaces of the highest quality.

Today, flatness or sphericity (deviation from an arbitrary best fit sphere) measurements are possible at the nanometre rms level, but a further improvement in these measurement techniques is needed to enable European industry to manufacture better surfaces for example for high quality mirrors or reference surfaces. In general, the surfaces must agree with the specified form within a few ten nanometres or even less. The capability of form measurement thus determines whether industry can produce these surfaces as specified by the optical design programs and whether high performance can be achieved.

Form measurements of aspheres and freeform surfaces and the measurement of the absolute radius of spherical sections have uncertainties that are larger by one to two orders of magnitude, because all

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three coordinates of the surface form have to be determined with a similar (high) accuracy, thus exponentially increasing the difficulty. Today, there is an increasing demand to measure surface slope angles larger than 25 to 30 degrees. Currently the uncertainty is not sufficient for these demands: For example, when measuring a small, locally flat surface area at an inclination angle of 30°, a lateral misalignment of 1 µm will cause a height error of half this value.

In 2009, the German Federal Ministry of Education and Research reported the increasing relevance of optics with the most demanding requirements [1], for instance, 'extreme UV-lithography (EUVL) plays an important role in the circuit development with structure sizes smaller than 32 nm.

Asphere surfaces of highest quality are used, for example, for beam shaping in synchrotrons, and will be used in the new European X-Ray Free-Electron Laser (XFEL). It is important for FELs, that the coherence and/or the wavefront of the source is retained [2] since any imperfections on the optical surfaces can degrade the quality of the radiation [3]. Conventional metrology tools for verifying the optical surfaces, like long trace profilers and conventional interferometers, are already close to their resolution limit. Further research and development is therefore required to properly specify mirrors for XFEL applications.

Currently, 1D-profilometers are often used for measurement of rotationally symmetric surfaces, however a lateral displacement of only a few micrometres from the centre will lead to unacceptable large errors. Since there is no perfect rotational symmetry, additional errors occur. Thus there is a need for 3D measurements with high lateral resolution.

Several optical measuring instruments are on the market which can measure aspherical or freeform surfaces relative to another surface or to a digital pattern in case of computer generated holograms, but the absolute measurement of optical surfaces with sufficiently low uncertainties approaching the nanometre level is not possible at present. Form standards are available, for instance, as flatness references, reference spheres or depth standards. But at present, no NMI can provide an aspheric form standard which is characterized in the 10 nm range.

For aspheres and freeforms, a true 3D measurement is necessary. 3D-tactile measurement is possible with CMMs, however conventional CMMs do not achieve the required uncertainty, and due to high probing forces, surfaces may be damaged in the measurement process. Recently, a new generation of microCMMs with point-to-point uncertainties below 100 nm and much lower probing forces have become available. However, measuring freeforms and aspheres with these microCMMs is not yet supported by a task specific uncertainty calculation based on a thorough understanding of the measurement process, including a better understanding of the probe surface interactions at these levels of uncertainty.

The challenge is to significantly improve optical surface measuring techniques to meet industrial needs for the highly accurate absolute measurement of optical surfaces, ranging from flats and spheres to aspheres and freeform. Important goals are to achieve uncertainties at the nanometre level for flat surfaces and about one order of magnitude higher for curved surfaces (aspheres and freeform).

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them, in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP protocol.

The main objective is to significantly improve optical surface measuring techniques for the highly accurate absolute measurement of optical surfaces, ranging from flats and spheres to aspheres and freeform.

The specific objectives are to:

1. Achieve uncertainties at the nanometre level (intention: < 1 nm pv / 0.25 nm rms) for flat surfaces and about one order of magnitude higher uncertainties for curved surfaces (aspheres and freeform). The size may vary from millimetres to a few hundred millimetres. Additionally, the lateral resolution is to be improved to tens of micrometres even for large samples of a few hundred millimetres.
2. Analyse error influences in interferometric concepts by thorough modelling. The systems to be analysed range from classical interferometric setups to deflectometry-assisted

multi-sensor techniques. For the interferometric measurement systems, reliable uncertainty calculations are to be carried out.

3. Establish guidelines for improving interferometric measurement concepts with special focus on error separation techniques.
4. Develop, realise, test and validate demonstrator setups and calibration standards.
5. Achieve improved form measurement accuracy by investigating error influences in tactile scanning methods and evaluating task-dependent uncertainty of complex form parameters by numerical simulation using the virtual CMM concept.
6. Compare imaging and scanning methods and establishing guidelines of their strengths and weaknesses in relation to the specific industrial applications.
7. Evaluate new software for the handling of a large number of data points to produce a comprehensive characterisation of the measured objects.

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links with the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project. In your JRP submission please detail the impact that your proposed JRP will have on any Directives.

You should also detail other impact of your proposed JRP as detailed in the document “Guidance for writing a JRP”.

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies
- transfer knowledge to the mechanical engineering, process engineering and production technologies, communication technologies, aerospace and glass (optical industries and sectors.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] http://www.bmbf.de/pub/nanode_report_2009_en.pdf

[2] L. Samoylova et al. : Requirements on Hard X-ray Grazing Incidence Optics for European XFEL, Proc. SPIE 7360 (2009), 73600E-73600E-9.

[3] M. Bowler, F. Siewert, B. Faatz, K. Tiedtke, Source: Investigating the effect of mirror imperfections in photon transport systems for FEL`s, Proceedings of FEL 2009 Liverpool.