

Title: Reference algorithms and metrology on aspherical and freeform lenses

Abstract

High quality optical surfaces are an enabling factor for many scientific and industrial applications, from precision engineering to the optical and semiconductor industries. The use of aspheres and freeform surfaces has grown considerably in recent years; these are the most challenging class of optical shapes and Europe has a leading role in their manufacture and metrology. A recognised measurement infrastructure for aspherical and freeform lenses is required in order to strengthen this lead, through the development of an accurate reference metrology chain, reference algorithms and standards, and significant advances in traceability to reach uncertainties lower than 50 nm.

Keywords

Optical surfaces, aspheres, freeform, reference algorithms, aspherical and freeform optical standards, traceability, form errors, optimal calibration strategies & design of experiment, interferometry, micro-CMM

Background to the Metrological Challenges

According to an analysis published by the European Commission [1], the computers, electronic and optical products sector is characterised by a strong global competition and a comparatively strong emphasis on R&D. The global market of the photonic industry is estimated to grow to 615 G€ in 2020, based on a market volume of 350 G€ in 2011 [2]. Europe has a strong position within this market, particularly in core sectors of production technology, optical components and systems, measurement and automated vision, medical technology and life sciences and defence and safety systems. However, the Commission's report also highlighted a number of weaknesses including a lack of standardisation and reference metrology chain.

Ultra-high accuracy optical components and systems represent a key technology for modern development in the photonics industry. The surfaces of the elements are of "optical high quality", i.e. smooth with very low roughness and waviness, with the characteristic property to describe these surfaces known as the 'form'. The most challenging class of optical surfaces are aspheres and freeform surfaces yet they have seen enlarged applications because their ability to reduce wavefront distortions and to eliminate spherical aberrations leads to unmatched optical performance.

The miniaturisation and mastering of form errors and surface quality of aspherical freeform optics, enabling improvements to industrial product performance and development of new smart applications, requires a corresponding improvement in measurement accuracy and traceability chain.

Dimensional metrology on these surfaces has been resolved to a sub-micrometre level (≤ 100 nm). However, in order to achieve traceability to SI unit of newly developed ultra-high precision measurement instruments, this level must be lowered to a few tens of nanometre (≤ 50 nm) by 2020 and a few nanometres by 2025.

Prior to their application, asphere and freeform measurement devices need to be calibrated. The accuracy and the reliability of subsequent measurements rely heavily on how the calibration has been performed, but optimal calibration strategies, reducing the amount of effort needed to achieve a required accuracy, are currently lacking.

An effective chain of traceability is urgently needed by stakeholders, which use different asphere and freeform metrology systems in their specific production environments to improve the accuracy of the surfaces. For this chain, the uncertainty at the NMIs also has to be reduced. Reference specimens must be made available to the stakeholders, and additional information on the behaviour of the instruments typically used is required.

Ongoing discussions at the High Level Expert Meetings and workshops of the Competence Centre for Ultra Precise Surface Manufacturing (UPOB) [3] on “asphere metrology” have strongly emphasised the urgent needs of industry for more accurate form measurement and improved asphere standards.

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 JRP shall focus on the traceable measurement and characterisation of aspherical and freeform lenses. Reference algorithms, reference aspherical and freeform standards, and measurement capabilities shall be improved to reach uncertainties smaller than 50 nm.

The specific objectives are

1. To develop reference algorithms to solve least square (L_2) and min-max (L_∞) minimisation problems, leading to ultra-precise fitting of aspherical and freeform optical lenses in order to extract their form errors, with a sub-nanometre calculation error. The reference algorithms shall include optimisation along both the tangent and vertical directions, to identify the parameters of the asphere model and the transformation surfaces. The most appropriate model to describe the shape of aspheres shall be identified by comparison of the standard ISO 10110, the Forbes models and the novel "hybrid" fitting method based on the curvature parameters.
2. To define and manufacture reference standards (aspherical and freeform optical surfaces) made of thermo-invariant materials. The reference standards shall be calibrated using ultra-high precision measuring machines and the calibration traceability shall be established.
3. To improve the metrological capabilities for aspherical and freeform optical surfaces using tactile and/or optical probing systems. Measurement uncertainty shall be reduced to less than 50 nm, over dimensions between 10 mm and 200 mm.
4. To investigate and compare data acquired by different measurement instruments. This shall include the interpolation between different surface representations, alignment techniques and stitching algorithms for freeform optics. The algorithms shall involve roughness analysis and improved filtering methods necessary for the comparison of measurements performed by different instruments. Thereafter, the developed reference algorithms shall be applied to data provided by the partners. An estimation of the uncertainty of the reconstructed form shall be established.
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the measurement supply chain (accredited laboratories, instrument manufacturers) and end users (photonics companies in medical, defence & safety, energy, telecommunications, aerospace and automotive sectors).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

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

In particular, proposers should outline the achievements of the EMRP project IND10 (Form metrology) ‘Optical and tactile metrology for absolute form characterisation’ and EMRP project SIB08 (subnano) ‘Traceability of sub-nm length measurements’ and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the medical, defence & safety, energy, telecommunications, aerospace and automotive sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”.

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. 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 EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

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

- [1] European Commission: Computers, electronic and optical products, Comprehensive sectoral analysis of emerging competences and economic activities in the European Union, <http://ec.europa.eu/restructuringandjobs>
- [2] Optech Consulting Study, Industry Report of Photonic 2013, <http://www.spectaris.de/photonikpraezisionstechnik/presse/artikel/seite/branchenreport-photonic-2013-wirtschaftsdaten-einerschlueseltechnologie/presse-1.html>
- [3] Competence Centre for Ultra Precise Surface Manufacturing (UPOB), <http://www.upob.de/>