Fabrication and Measurement of Large Scale Freeform Optics

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Abstract: Utilizing freeform optics in an optical system improves the system's overall performance and form-factor. These benefits come at a cost, both financial and technical, as freeform optics require advanced design, fabrication, and testing methods. © 2019 The Author(s)

OCIS codes: 220.0220, 120.0120.

1. Introduction

Employing freeform surfaces in an optical design can greatly improve the system's ability to meet the performance goals. Typically, by introducing freeform surfaces, one can obtain a larger field of view, smaller packaging volume, or increased imaging resolution. However, these benefits come at a cost, both financial and technical. Freeform surfaces require additional fabrication, testing, and alignment methods that can be more time consuming and costly compared to traditional surfaces.

2. Freeform Optics Fabrication and Testing

2.1. *Freeform Optics Design Considering Manufacturability*

When choosing to use a freeform in an optical design, we should be judicious in our application, maximizing their impact. To guide this freeform surface selection process, we have developed a parametric fitness function using modal wavefront fitting [1, 2]. The fitness function combines metrics from aberration control to manufacturability to help the designer objectively choose which surface in their design will optimally impact the design performance outcomes. As presented in Fig. 1, optical designers are able to incorporate the impact of their freeform surfaces on the fabrication and testing of the system, not just the optical performance, in their design methodologies.

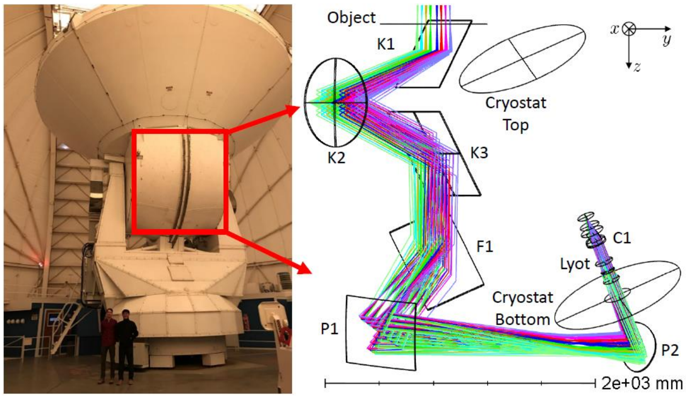

Figure 1. The millimeter-wave instrument design created for the Tomographic Ionized-carbon Mapping Experiment (TIME) using the 12 m Radio Telescope at Kitt Peak. The folded beam path was required to achieve a target form-factor within the cabin space, and as such needed freeform optics to meet the science-driven optical performance. This design was originally optimized using human intuition and successfully benchmarked to demonstrate the capability of the fitness function-based freeform optical design method. The surfaces K2, P1, P2, and C1 are freeform while the surfaces K1, K3, and F1 are flat. [1]

2.2. *Gradient Polynomials for Freeform Optics Data Processing*

One of the challenges for fabrication and measurement of freeform optics is the ability to mathematically describe, analyze, and/or reconstruct such surfaces. Whereas a description based on a modal polynomial basis set can be useful, it often suffers practically from not being able to numerically generate and compute many polynomial terms. We have developed a mathematical framework and implemented it in software, to describe optical surfaces/wavefronts in terms of gradient polynomials [2]. These can fit slope data in the gradient domain, which is the measurement domain for various direct slope measurements such as deflectometry and Shack-Hartmann Wavefront Sensor measurement. Our model, based on gradients of two-dimensional Chebyshev polynomials of the first kind, can easily generate and fit up to hundreds of thousands of polynomials (called **G** polynomials). This ensures that the surface is reconstructed accurately, which is even more useful if we are interested in preserving high-resolution information, for describing freeform surfaces and for special practical metrology problem solutions (e.g., surface reconstruction in the presence of markers such as fiducials or spiders in telescope apertures) [2]. Although **G** polynomials are orthogonal across rectangular apertures, their ability to efficiently employ a very large number of modes enables accurate fitting for various aperture shapes or unevenly sampled data [3].

2.3. Infinite Deflectometry for Freeform Optics Metrology

Near flat to convex freeform surface represent a particularly challenging metrology region. Deflectometry offers a non-null test method that can produce results comparable to interferometry and can measure complex aspheric/freeform surfaces [4, 5]. However, testing convex or large flat optics requires an extremely large source area to measure the full optical aperture. Infinite deflectometry solves this problem by instead tilting a precision source over the unit under test (UUT), which is on a rotation stage, with a camera focused on the UUT. As the UUT is rotated, a series of virtual screens are created and a virtual 2π steradian measurement volume is created around the UUT. This allows for high accuracy deflectometry of freeform and convex optics. A small-scale case study of the technique demonstrates the ability to accurately measure a highly freeform Alvarez lens as presented in Fig. 2. For large optics applications, the infinite deflectometry can be scaled up using a large format screen such as an off-the-shelf 65-inch LCD television.

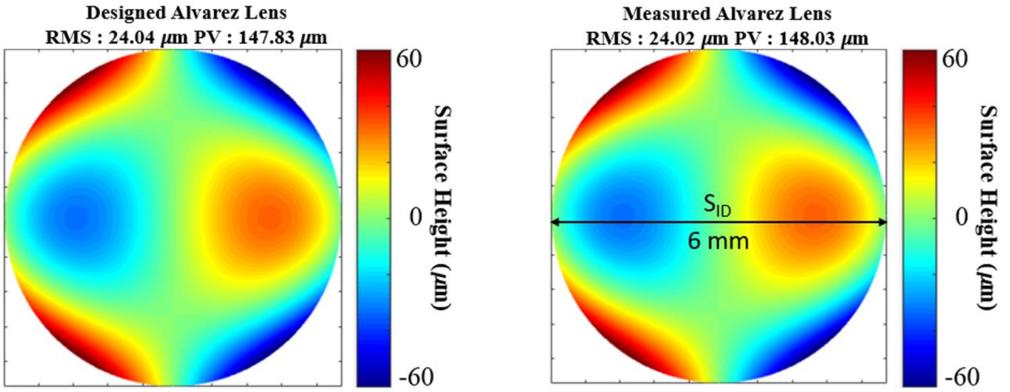

Figure 2. An Alvarez lens was designed and generated on a PMMA disk (left). Due to the highly freeform nature of the lens, it was impossible to measure without a custom CGH using interferometry. The infinite deflectometry technique successfully measured the surface (right). As a verification of the method, a profile of the surface was measured using a touch tip profilometer and compared to the profile from the infinite deflectometry reconstruction map. The RMS difference between the methods was 488 nm. [5]

3. References

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