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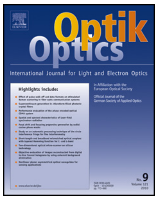

Research of aberration characteristics of conicoidal conformal optical domes

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ABSTRACT

Most conformal optical system designs concentrate on the researches of ellipdoidal domes. However, ellipsoidal domes are not the best ones which possess excellent aerodynamic performance among conicoidal conformal domes. This paper investigates the aberration characteristics of conicoidal conformal domes. For the purpose of the study, different types of infrared conformal domes, including ellipsoidal domes, parabolic domes and hyperbolic domes, with the common fineness ratio of 1.0 and an index of refraction of 2.25 are modeled by mathematical computation. To investigate the dynamic characteristics of the on-axis aberrations, the curves of third order fringe Zernike polynomials of the domes across field of regard are obtained by decomposing the incident wavefront at the exit pupil. The Zernike aberrations across field of view are also achieved to investigate the varying characteristics of off-axis aberrations. To find the similarities and difference between spherical domes and conformal domes at both field of regard and field of view, also make the foundation for optical design, spherical domes and defocused spherical domes are modeled for reference researches. The changing rules and the features of the aberrations among different types of conicoidal conformal domes are drawn as conclusions at the end of the paper.

1. Introduction

For a long time, optical domes have been sections of concentric spheres or hemispheres. Spherical domes introduce small aberrations and facilitate fabrication. However, this type of domes does not satisfy the demand of low air resistance when the missiles flying at high speed. We are entering an era where the design norms of the past must change to accommodate increasing aerodynamic performance goals. New domes are designed to take optical as well as aerodynamic performance into account. Conformal optical domes are the ones designed with regard to the aerodynamic performance as the primary consideration and the optical imaging properties as the secondary concern. Therefore, this new kind of domes possesses the merit of low air drag and will certainly become a new research topic [1–6].

The aerodynamic performance of an optical missile dome can be associated with the outer surface and its fineness ratio, which we defined as the ratio of the length to the diameter of the dome. At the level of recently optical manufacturing and testing, conicoidal optical domes can be manufactured without much trouble. Other conformal domes, like polynomial surfaces and spline surfaces, cannot be easily made with high quality. Ellipsoidal domes are always the researching object in conformal optical system [7–9]. However, this type of domes is not the best ones which possess excellent aerodynamic performance among conicoidal domes. Both of the parabolic domes and hyperbolic domes generate lower air resistance than ellipsoidal domes. However, far too little attention has been focused on the aberration research of parabolic domes and hyperbolic domes [10]. In order to put conicoidal domes into application, the research of the aberrations introduced by conicoidal optical domes seems important.

Since the conformal optical domes lose rotational symmetry compared with spherical domes at nonzero field of regard (FOR), traditional Seidel aberration theory cannot be used to exactly evaluate the imaging quality of conformal optical systems. Consequently, Zernike aberration theory was used in this paper to evaluate the imaging quality by decomposing the incident wavefront at the exit pupil. We have used a perfect lens behind the conformal dome to investigate the aberration characteristics of the domes. Since the perfect lens introduces no aberrations, all the aberrations are introduced by the domes. We have also identified the perfect lens as the stop of the system and fixed the field of view to 2° in each case. We rotated the perfect lens to different angles within each of the domes to investigate the aberrations introduced by the domes

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across the FOR. We modeled each dome as 4 mm ZnS with an analysis wavelength at 4 μm.

In the following sections of this paper, we present the third order Zernike aberrations of conicoidal conformal optical domes at different FOR and field of view (FOV). To further understanding the dynamic characteristics of the aberrations, we also investigate the aberrations of spherical domes and defocused spherical domes for reference researches. We characterize the common aberrations of conformal optical domes and show that similar aberrations can be found in the defocused systems, which can be made as the foundation for conformal optical design.

2. Theory and analysis

2.1. Aberrations of centered spherical domes

A centered spherical dome optical system was modeled as shown in Fig. 1. The outer and inner surface centers of curvature are coincident. The outer diameter of the dome is 180 mm, the thickness of the dome is 4 mm from the vertex to the edge of the dome. The gimbal point in such system is located at the centers of curvature, creating an axially symmetric optical system that is constant with respect to gimbal angle. The perfect lens is set as the aperture stop with the F/# of 2.0, as in the following optical system.

A plot of the third order fringe Zernike polynomial coefficients across the FOR is shown in Fig. 2. As shown in Fig. 2, the only nonzero curve is that associated with the third order spherical term because the plot was done for the on axis or zero field case. The field dependent aberrations, like astigmatism and coma, are zero. Third order astigmatism and coma are plotted as a function of FOV in Figs. 3 and 4, respectively. As shown in these figures, astigmatism is small and not a concern. Coma is comparatively larger than astigmatism, but also slight.

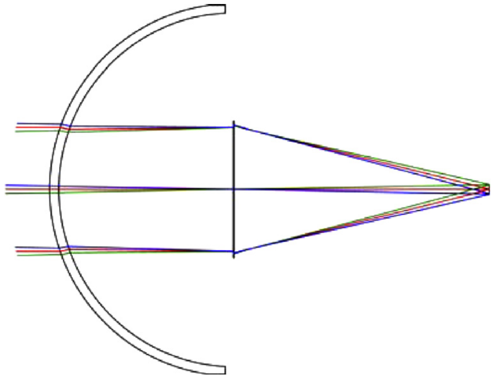

Fig. 1. A centered spherical dome optical system.

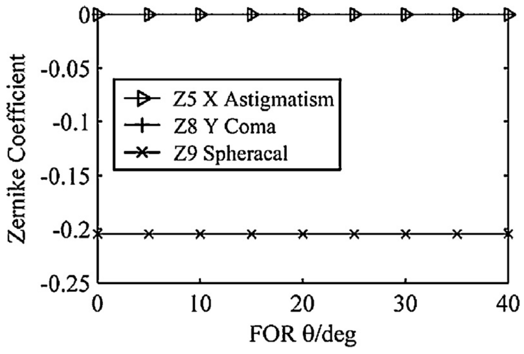

Fig. 2. Third order on-axis fringe Zernike polynomial coefficients for a centered spherical dome.

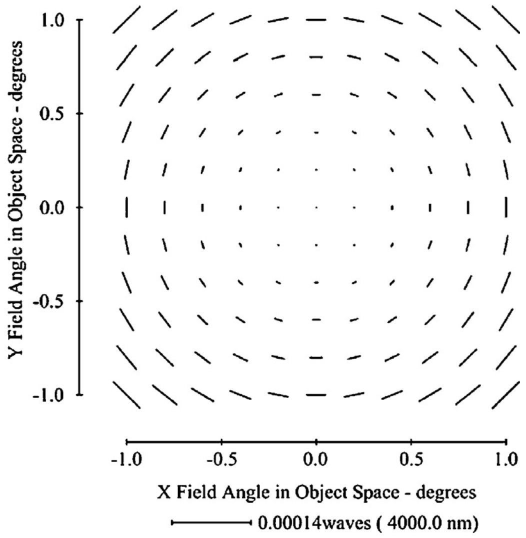

Fig. 3. Third order astigmatism for a centered spherical dome.

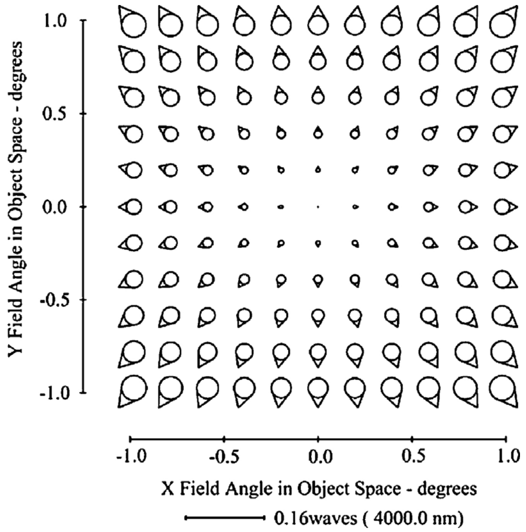

Fig. 4. Third order coma for a centered spherical dome.

2.2. Aberrations of defocused spherical domes

It is helpful for us to study the aberrations of defocused spherical domes, although almost every spherical dome design uses it in its point symmetry condition. As a practical matter, it is difficult to achieve the perfect rotationally symmetric surfaces once the spherical dome optical system defocuses and the gimbal angle sets at non-zero FOR. Many of the lessons learned in studying the defocused optical domes apply directly to conformal domes as well. We defocused the perfect lens along the optical axis to make the perfect lens 20 mm away from the center of the spherical dome, which creating a defocused spherical dome optical system as shown in Fig. 5. All other parameters are identical to the centered system.

We again plotted the third order an-axis aberrations for the system as a function of gimbal angle in Fig. 6. As shown in Fig. 6, the aberrations changes with the varying of gimbal angle over the FOR. It means different parts of the dome introduce different amount of aberrations. The astigmatism and the coma begin at zero and gradually increase as the perfect lens rotates from the vertex to the edge of the dome. The spherical surface which the rays travel through at 0° gimbal angle gradually changes into aspherical surfaces with the increasing of FOR. The spherical aberration only varies a