Correcting aberration in aspheric surfaces

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Abstract. New technique eases aspheric lens fabrication and overcome traditional limitation. An aspheric lens has been designed by using optical designing software to replace the achromat (Doublet) lens of eyepiece assembly of telescope. The devised physical parameters of aspheric lens have been incorporated into the CNC Aspheric machine to fabricate the lens. The antireflection coating for visible region has been carried out on lens by employing PVD technique. In this report diminished aberration effects due to non-spherical surface profile and comparison of optical parameters of achromat (doublet) and aspheric lens is presented.

1. Introduction
The advantages of utilizing aspheric surfaces in optical design have long been known. However, advances in optical manufacturing technology have opened up a new world of possibilities to the optical designer.

An aspheric lens is a rotationally symmetric optics with one or more surfaces having a non-spherical surface outline. This unique feature allows aspheric lenses to deliver improved optical performance, eliminating spherical aberration and greatly reduce other aberrations when compared to a simple spherical lens [1].

The software can easily and quickly produce a result for an aspheric that will improve a lens design. The designer can find only solutions that are manufacturable. Manufacturing technologies for aspherics have improved significantly over the last decades. Very accurate optical surfaces can be produced with exceptional quality. New methods like high speed computer controlled disc grinding have enabled machining methods to produce aspheric surfaces in brittle optical materials.

One more aspect is very important for optical assembly; utilizing aspheric surfaces in the design of an optical system can reduce the number of optical surfaces to process while achieving a more highly corrected imaging performance. To the designer, this mean an optical system with better performance, lighter weight, less fabrication time, and reduced tolerance restriction is possible now.

However, Interferometry has been the standard method of testing surface accuracy of conventional spherical optics since Newton’s time. Still noncontact metrology of aspheric surface accuracy is not fully realized and is coming close to fruition [2]. So, the surface profilometer is the only choice to measure aspheric accurate profile without special tooling.

In this report, development of aspheric with the help of designing software and correction of spherical and chromatic aberrations due to aspheric surface contour is considered. The detailed comparison of optical parameters of achromat (doublet) and aspheric lens and their theoretical and experimental results are discussed.
2. Designing and manufacturing of aspheric lens
The standard way of representing a rotationally symmetric aspheric surface is given by [3-7]:

\[ Z = \frac{C x^2}{1 + \sqrt{1 - (K+1)C^2 x^2}} \]  

(1)

Where \( C = 1/\text{radius of curvature} \), \( K = -e^2 \) and \( e \) is the eccentricity of the conic surface. The nature of conic surface depends upon the value of \( K \): e.g., sphere: \( K = 0 \), ellipsoid: \( K > -1 \), paraboloid: \( K = -1 \), hyperboloid: \( K < -1 \).

Optical designing software allows designers significant design freedom to use aspheric terms on every surface in an attempt to coverage the optimal design solution. The software can easily and quickly produce a result for a manufacturable asphere that will improve a lens design. The aspheric surface is designed using the equation 1 in the optical designing software. The design is optimized indicating the shape of aspheric as hyperboloid. The design parameters of the aspheric plano-convex lens are explained in the table 1:

| Parameter                   | Dimension  |
|-----------------------------|------------|
| Radius of curvature (Side-1)| 50.23 mm   |
| Radius of curvature (Side-2)| ∞          |
| Conic constant (K)          | -2.3       |
| Diameter of lens            | 41.55 mm   |
| Centre thickness            | 17.55 mm   |
| Optical material            | K9         |

The ray tracing of the aspheric lens is shown in figure 1.

![Figure 1. Ray tracing of aspheric lens](image)
3. Results and discussions

Figure 2 shows the comparison of defocusing effect on point spread functions for a peak-to-valley OPD (wave-front deformation) of a quarter-wave for doublet and aspheric lenses. It can be seen that the defocusing effect for aspheric lens (figure 2. (b)) with Strehl ratio equal to 0.51 is reduced as it obeys the Rayleigh criterion which is the OPD equal to a quarter-wave is identical to the Marechal criterion (Strehl ratio equal to 0.80) while for doublet lens (figure 2. (a)) the Strehl ratio is 0.37 which is away from Marechal criterion indicating the sharpness and height of the peak is low as compared to the aspheric lens.

![Figure 2](image)

(a)                (b)

Figure 2. Comparison of point spread function for doublet and aspheric lenses.

Figure 3 shows the focused spot size for doublet and aspheric lenses. It can be seen that in case of aspheric lens (figure 3. (b)) the spot size is focused up to a value of 0.34 mm whereas for doublet lens (figure 3. (a)) its value is 0.55 mm. It can be concluded that the focused spot in case of aspheric lens is very sharp whereas it is defused in case of doublet lens. The sharpness of the focused spot size for aspheric lens (figure 3(b)) is attributed to reduction in the aberrations while for doublet (figure 3(b)); the defused spot size is due to the presence of the aberrations.

![Figure 3](image)

(a)                (b)

Figure 3. Comparison of focused spot size for doublet and aspheric lenses.

Figure 4 shows the comparison of transverse aberration fan for doublet and aspheric lenses. It can be seen that the transverse aberrations for doublet (figure 4 (a)) are much more than the aspheric lens (figure 4 (b)). As explained in [8] the transverse measure of an aberration is directly related to the size...
of the image blur. By comparing the figure 3 and figure 4 it is clear that the image quality in case of aspheric lens is much better than the image quality in case of doublet.

![Figure 3](image1.png) ![Figure 4](image2.png)

**Figure 4.** Comparison of transverse aberration fan for doublet and aspheric lenses.

The manufactured aspheric lens was replaced with the doublet lens in the eyepiece assembly and measured optical parameters are listed in Table 2.

| Parameter                        | Doublet Lens | Aspheric Lens |
|----------------------------------|--------------|---------------|
| Exit Pupil Diameter             | 5.2 mm       | 5.2 mm        |
| Resolution                      | 4.12"        | 4.12"         |
| Focal Length of eyepiece        | 28.07± 0.5 mm| 28.06± 0.2 mm|
| Field of View                   | 6.1°         | 6.1°          |
| Exit Pupil Distance             | 22 mm        | 22 mm         |
| Magnification                   | 11.76        | 11.8          |
| Focal Length of Individual Lens | 98.12 ±0.6 mm| 97.99 ± 0.2 mm|

By comparing the optical parameters of both lenses given in table 2 it can be seen that almost all the parameters are same except the minor differences in the focal lengths of individual components as well as the eyepiece assembly. It can also be concluded that the deviation in focal lengths is minimum for aspheric lens than the doublet lens in both cases.

4. **Conclusions**

The development of aspheric lens provides the advantages over the achromat (doublet) lens such as reduction in optical components, manufacturing time as well as weight, more compact, improved in image quality (minimize aberrations), cost effective in the eyepiece assembly. However the short coming in the measurement of surface accuracy method is still in developing phase.
5. **Acknowledgement**
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6. **References**
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