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Designing the optimal Fresnel lenses by using Zemax software

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Abstract: In this paper, the optimal Fresnel lenses are designed by Zemax software. The fundamental problem of the Fresnel lenses is the beam divergence, which was resolved by decreeing the output stain diameter on the image plane. For this purpose, two types of radial and cylindrical Fresnel lenses are simulated with different grooves using Global and Hammer optimization methods. The minimum output stain diameter in radial and cylindrical modes are computed for Fresnel surfaces and different components of the Fresnel lenses. The Results show that the Fresnel lenses have a spherical and distortion aberration. By optimizing the optical system with the Global and Hammer methods, the output stain diameter can be controlled and the beams are focused. Numerical results and conclusions are given in our paper by changing the distance between the elements, radius, material, height, depth and width of the Fresnel lenses in two modes using sequential and non-sequential components.

Keywords: Fresnel Lenses, Optimization, Stain Diameter, Hammer and Global Method.

1. INTRODUCTION

Nowadays, the bulky and old lenses are replaced by thinner and flattened lenses with less light absorption. The construction of a thinner and lighter lens was proposed by Georges-Louis Leclerc and the first step lens was built by Comte de Buffon and co-workers in 1748 [1]. The Fresnel lens was invented by Augustin-Jean Fresnel and was first used in lighthouse which attracts more light and can be seen at far distances [1]. The Fresnel lens is a flat surface that focuses beam by grooves. The primary Fresnel lenses were made of glass and were considered as an appropriate alternative to optical systems [2,3,4]. The aperture of the Fresnel lens is very large and beam absorbing is very low. In the past, the old problem of these lenses is the beam divergence and the material

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thickness, thus it is not used in imaging systems. The grooves near the center of the Fresnel lens are fairly flat and shallow and the grooves near outer points of the Fresnel lenses have sharp and deep angles [5,6]. In Fresnel lenses each groove represents a prism [7], so the Fresnel lenses contain a set of prisms which the fracture of the light in the Fresnel lens is obtained based on the prism's rules [8,9]. Any deviation in the Fresnel lens causes a high deviation in the beam [10]. The greater the grooves' angle aligned with optical axis so the focal length will be smaller [11]. Nowadays, the importance of the Fresnel lenses is seen in projectors, increasing solar cell efficiency and the output stain diameter emission beam can be reduced by optimization in order to be used in imaging systems [12].

In this paper, the optimal Fresnel lenses are designed in two modes using sequential and non-sequential components in Zemax software version 2005. At first beam propagation through the Fresnel lens is simulated and then the output stain diameter on the image plane is minimized using optimization by two methods.

2. BASIC CONSEPTS

In the new optical imaging systems, the beams first pass through the Fresnel lens and then focused by two lenses on the image plane [10,13].

The classification of the Fresnel lenses according to the output beam and the grooves position includes collector, collimator and divergent (As shown in Fig. 1) [12,14]. In Zemax software the Fresnel lenses are radial and cylindrical, and only a beam collector is used (As shown in Fig. 1.a), because the Fresnel lenses are convex [11].

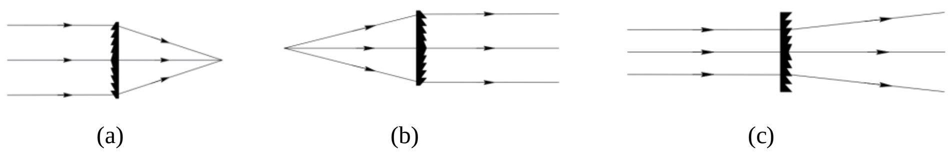


Fig. 1. (a) Positive focal length Fresnel lens as a collector (b) Positive focal length Fresnel lens as a collimator (c) Negative focal length Fresnel lens as a divergent [12].

In Zemax software with the lens width definition, it is possible to design the Fresnel lens in radial and cylindrical modes, it is obvious that the width of the radial Fresnel lens is zero [10,11]. Radial Fresnel lenses are concentric circles and cylindrical Fresnel lenses are rectangular [2,15-17]. The value of +Depth/-Frequency grooves in Zemax software is important and is described: "If this parameter is positive, then it corresponds to the depth of each groove in lens units. If negative, then it corresponds to the frequency of the grooves [11] ". In this simulation for a radial Fresnel lens +Depth/-Frequency value equals to 2 (47 grooves) and for cylindrical lens +Depth/-Frequency value equals to - 0.8 (79 grooves) which represents the number of grooves at the Fresnel lens diameter. The relations (1), (2) and (3) optimize the width of the grooves (d) and the lens diameter (Φ) [8]:

$$\Phi = \frac{m.h}{(1+\frac{m.s_1}{l-s_1})} \quad (1)$$

$$d \approx 1.5\sqrt{\lambda f} \quad (2)$$

$$d \leq p.\tan(\frac{1}{60}^{\circ}) \quad (3)$$

Where λ is the wavelength of the radiation emitted from the source, f is the Fresnel lens focal length [18,19], s_1 is the distance between the lens and the object, m is the Fresnel lens magnification, l is the distance between the object and the observer and p is the distance between the observer and Fresnel lenses (As shown in Fig. 2.).

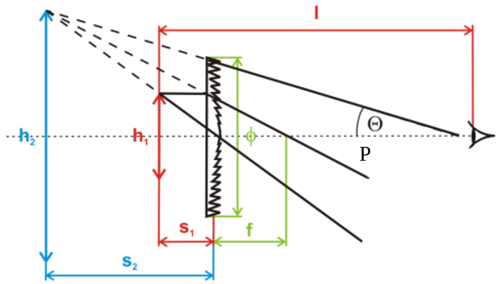


Fig. 2. A symbolic layout of Fresnel lens [8].

The h_2 and s_2 coefficients are related to the image. According to Eq. (3): "A typical healthy human eye has a visual acuity of around 1 arcminute ($\tan(\frac{1}{60}^{\circ})$) [8] ". Also, from the Newtonian equation for the Fresnel lens, the focal length is described [6,8]:

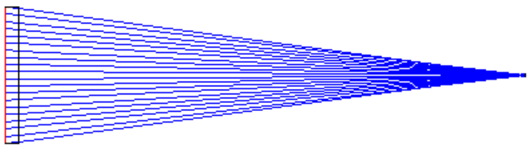
$$f = \frac{s1}{1-\frac{1}{m}} \quad (4)$$

We can use an approximation in Zemax software, so the grooves are considered infinite. In this case, the Fresnel 2 component is used in non-sequential systems [11]. Aberration in an optical system means that the optical system is not ideal. The aberrations of the optical system are known as Seidel aberrations. The Seidel aberrations include Spherical, Coma, Astigmatism, Curvature and Distortion. In the Fresnel lenses there are spherical and distortion aberrations. Aspherical aberration is an optical effect observed in the optical components (lens, mirror, etc.). This effect occurs when light beams incident on the edge of the lenses. Distortion aberration means the magnification is not identical in all points of the image [20]. In Zemax software, distortion aberration is investigated using output stain on the image plane. If the output stain formed on the image plane does not have the same beam distribution, then the system has a distortion aberration. In Zemax software the Hammer and Global optimization methods are used for decreasing aberration. These methods are very identical and share same functional basis. Their main difference is that the Global method's output derived from ten other optimization systems' output which one of them is adopted with regard to the problem. In optimization process, firstly, take wanted elements as variables, and then their scope is restricted using merit functions in Zemax software. Then the optimization methods are simulated by tool section [11].

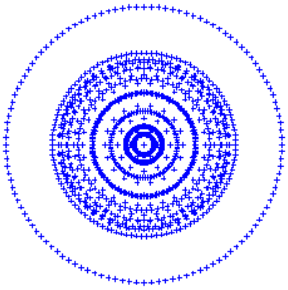
3. SIMULATION

In this section, the Fresnel lenses are simulated in two radial and cylindrical modes using sequential components (Fresnel surfaces) and non-sequential components. Fresnel lens simulation using Fresnel surfaces is as follow:
At first, the output stain diameter is 900 (μm) and the distance between standard surface and image plane is 210.252 (mm). With optimization using Hammer method in sequential components, the minimum output stain diameter reached 160 (μm). For sequential components using the Fresnel surface, the number of grooves are considered infinite and the grooves angle aligned with the optical axis (Z axis in Zemax software) is also zero [11]. The system is completely sequenced. The beams after passing through the Fresnel and standard surfaces, appeared on the image plane. The Fresnel surface is determined as the input aperture. The distance between source and Fresnel surface is infinite. The Fresnel lens thickness is 5 (mm) and after optical system optimization using the Hammer method, the distance between standard surface and image plane is 185.784 (mm). The diameter of Fresnel and standard surface are 50 (mm). The lens material is bk7, which has very low dispersion. Refractive index of bk7 is 1.517 and V-number is 64.169 [10,12]. The wavelength of the incident beam is 550 (μm). The circular image plane has also been used with a radius of 0.252 (mm). The curvature radius considered for the

Fresnel surface is 100 (mm) and for the standard surface is infinite. In this simulation, the optimization method is applied to the Hammer method using the distance variation between the standard surface and the image plane in Zemax software. The design of this optimal simulation and the output stain diameter using Fresnel surface are shown in Fig. 3. Also, we used 20,000 beams to obtain more information from the image plane.



(a)

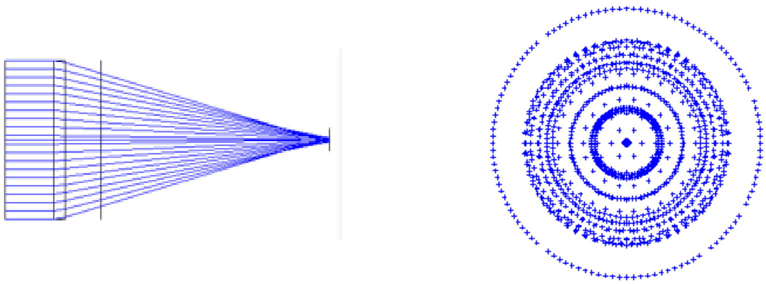


(b)

Fig. 3. (a) Simulation of Fresnel lens in sequential mode using Fresnel surface in Zemax software and (b) the stain obtained by the output rays on the image plane.

For non-sequential components we used Fresnel 1 and Fresnel 2. Fresnel lens simulation using non-sequential component of Fresnel 2 (use infinite grooves) is as follow:

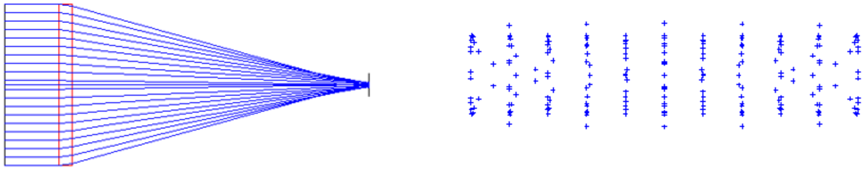
At first, the output stain diameter of the radial Fresnel lens is 1112.34 (μm) and the radius of the Fresnel lens is 75 (mm) and the distance between Fresnel lens and image plane is 100 (mm). The lens material is bk7 and the Fresnel lens thickness is 5 (mm). The distance between source and Fresnel lens is 20 (mm). After optimization using the Hammer method the distance between Fresnel lens and image plane is 95 (mm) and the radius of the Fresnel lens is 63.7 (mm). The wavelength of the incident beam is 550 (μm) and the diameter of the lens is 60 (mm) and the width of the Fresnel lens is 40 (mm) in cylindrical mode and the angle of grooves with optical axis is zero and image plane is square with a total area of 16 (mm^2). The design of the optimal radial Fresnel lens and the output stain diameter are shown in Fig. 4. and the optimal cylindrical Fresnel lens and the output stain diameter are shown in Fig. 5. Also we used a surface with a hundred percent transmission to indicate the location of the beam on the image plane.



(a) (b)

Fig. 4. (a) Simulation of the radial Fresnel lens using the non-sequential component of Fresnel 2 in Zemax software and (b) the stain obtained from the output rays on the image plane.

In Fig. 4.b the output stain diameter is spherical and symmetric, so in Zemax software it leads to the optical system with a spherical aberration. It is obviously because the spherical aberration is the variation of the focal length with diameter of the lens and all the beams are not paraxial. However, the small value of the output stain diameter (628.851 (μm)) results in utilization of radial Fresnel lenses in photography.



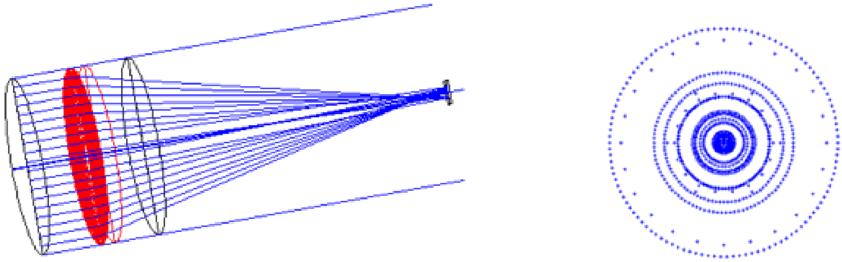
(a) (b)

Fig. 5. (a) Simulation of the cylindrical Fresnel lens using the non-sequential component Fresnel 2 in Zemax software and (b) the stain obtained from the output rays on the image plane.

Fresnel lens is named according to stain geometry. Radial Fresnel lens include circular stains and cylinder Fresnel lens include rectangular stains [2,11]. In Fig. 5.b the output stain diameter is symmetric, so in Zemax software it leads to the optical system with a spherical aberration. Also, distribution of the rays is not the same in all points, so in Zemax software it leads to the optical system with distortion aberration.

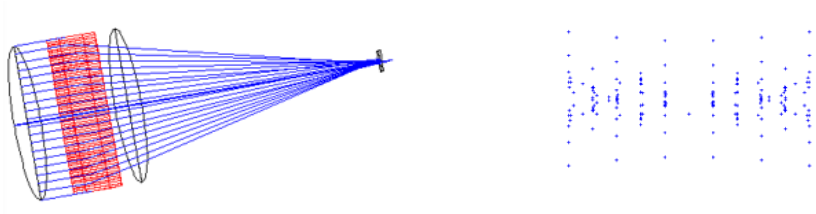
The radial Fresnel lens using the non-sequential component of Fresnel 1 (As shown in Fig. 6. a) and the output stain diameter on the image plane (As shown in Fig. 6. b) and the Cylinder Fresnel lens using the non-sequential component of Fresnel 1 (As shown in Fig. 7. b) and the output stain diameter on the image plane (As shown in Fig. 7. b) are simulated in Zemax software. Simulation of Fresnel lens using non-sequential component of Fresnel 1 is as follow:

At first the output stain diameter on the image plane in the radial mode is 1.642 (mm) and in the cylindrical mode is 3.324 (mm). The distance between Fresnel lens and image plane is 110 (mm). Also the radius of the Fresnel lens is 75mm. The lens material is bk7 and Fresnel lens thickness is 5 (mm). The diameter of the lens is 60 (mm) and the width of the Fresnel lens is 40 (mm) and image plane is square with a total area of 16 (mm^2). The wavelength of the incident beam is 550 (μm). The distance between source and Fresnel lens is 20 (mm) and the distance between Fresnel lens and image plane after optimization using the Hammer method is 100 (mm) and the radius of Fresnel lens is 63.7 (mm).



(a) (b)

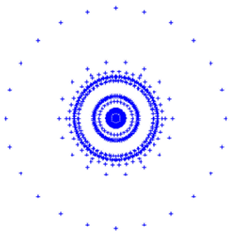
Fig. 6. (a) Simulation of the radial Fresnel lens using the non-sequential component of Fresnel 1 in Zemax software and (b) the stain obtained from the output rays on the image plane.



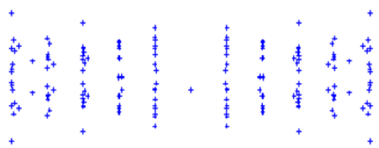
(a) (b)

Fig. 7. (a) Simulation of the cylindrical Fresnel lens using the non-sequential component of Fresnel 1 in Zemax software and (b) the stain obtained from the output rays on the image plane.

In this case for a radial Fresnel lens, +Depth/-Frequency value equals to 2 (47 grooves) and for cylindrical Fresnel lens, +Depth/-Frequency value equals to 0.8 (79 grooves). In Fig. 6.b the output stain diameter is spherical and symmetric, so in Zemax software it leads to the optical system with a spherical aberration. In Fig. 7.b the output stain diameter is symmetric, so in Zemax software it leads to the optical system with a spherical aberration. Also, distribution of the rays is not the same in all points, so in Zemax software it leads to the optical system with distortion aberration. Now in the merit functions section in Zemax software which is related to optimization in the Global method, by changing radius and thickness of the Fresnel lens, the distance between Fresnel lens and image plane and the width of the grooves, the optimal output stain diameter on the image plane in the radial mode is 1.138 (mm) (As shown in Fig. 8.a) and in the cylindrical mode is 2.638 (mm) (As shown in Fig. 8.b). After optimization the effective focal length of the optical system reached 122 (mm), which is a small value. The design of this optimal radial and cylindrical Fresnel lens using the non-sequential component of Fresnel 1 are shown in Fig. 8.a and Fig. 8.b.



(a)



(b)

Fig. 8. (a) The stain obtained from the output rays in radial mode on the image plane after optimizing the Fresnel lens and (b) the stain obtained from the output rays in cylindrical mode on the image plane after optimizing the Fresnel lens.

4. CONCLUSION

Designing the smaller and lighter lenses in optical systems have several applications such as in the solar cells to increase the efficiency also in imaging systems. The fundamental problem of the Fresnel lenses is the divergence of the beam, which was resolved by decreeing the output stain diameter on the image plane in this work. In this simulation the output stain diameter on the image plane was examined and represented the aberration of the optical system. The results show that a slight change in the Fresnel lens elements such as thickness, width of the grooves and radius of the Fresnel lens and the distance between the elements cause a change in the effective focal length and the output stain diameter on the image plane. By changing the elements in the simulation, the beams were focused and made the converging Fresnel lens be used in photography. Also, according to Zemax software the results show that the Fresnel lenses have a spherical and distortion aberration, so by optimizing the optical system in the Global and Hammer methods, the value of these aberrations were minimized and a large number of beams were focused.

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