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Xenon Lamp based Broadband Light Source with a High-uniform Beam Profile using an Ellipsoid Reflector

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A uniform beam profile is widely used in optical applications as spectroscopy, surface metrology, and imaging systems. It is easily achieved with a narrow spectral laser source using a lens system. However, it is a challenge with a broadband spectral light source because of the different refractive index of the lens with respect to each wavelength which caused chromatic aberration. In this study, we propose an efficient method to obtain a high-uniform beam profile based on the broadband spectral light source by using a Xenon lamp and an ellipsoidal reflector. A donut-shaped beam profile of the ellipsoidal reflector configuration is thoroughly solved by a holographic diffuser. The enhanced output beam profile is evaluated by a good agreement between the experiment and simulation result. The high-uniform beam profile with the broadband light source is demonstrated when using the ellipsoidal reflector.

NOMENCLATURE

D = Holographic diffuser
L = Plano-convex lens
CCD = Camera
f = Focal point

1. Introduction

Illumination system plays a vital role in precision measurement and precision machining. In an inspection system, for example, an image taken with a non-uniform light source will have higher energy areas, which might lead to misidentification of some expected characteristics of the sample [1]. At present, the uniform distribution is obtained simply with a laser source. Some technologies can be mentioned as binary optical element shaping, homogenizer diffractive optic elements, optical fiber shaping and aspheric surface shaping can rearrange the beam distribution from Gaussian profile to uniform profile [2]. However, in some broadband spectrum inspection experiments, the required characteristics of the illumination system are wide spectrum range, good collimation, good uniformity and high power. These essential characteristics are difficult to achieve with one laser source.

In this study, we develop an illumination system with a wide spectrum range from UV to IR and high-uniform distribution. An ellipsoidal reflector is used to collect maximum the light from a Super-quite Xenon lamp. The uniform beam will be obtained by using two homographic diffusers and collimated after two collimating lenses.

2. Experiment setup

In this configuration, to achieve light with high efficiency, people usually use the following two types of reflectors: paraboloidal and ellipsoidal reflector. Paraboloidal reflectors collect the light from the source at its focal point and reflect it as a collimated beam, parallel to the axis. In general, these reflectors are used for long distance transmission. Ellipsoidal reflectors have two conjugate focal points. The light from one focal point after reflection is focused at the other. These kinds of reflectors are used for collimating the light. In this study, an ellipsoidal reflector is applied to improve the power efficiency of the xenon lamp which is placed at the first focal point f1. However, because of the reflector's geometrical characteristics and it has a small hole in the back to place the lamp bulb, that position cannot reflect the light, so the beam shape after the focal point f2 is

Gaussian distribution and appears a dark center in the middle. Thus, the beam after f2 becomes a donut shape. There are several ways to create the uniform distribution: light pipe, beam shaping, diffuser, etc. The light pipe has a high-quality uniform output beam and low cost, but it can only create uniform distribution in the near field. Beam shaping, nowadays, is also a popular technology to get a uniform beam. The commercial products are available from many vendors with high transmission efficiency and high uniform distribution. However, the input beam has to be a plane wave and is only available for a single wavelength such as a laser source. The diffusers are used in this configuration because it has high transmission efficiency, wide spectrum and high uniform distribution but it needs a short distance. In order to compensate for this limitation, two diffusers are proposed with diffuser D1 is placed right after the second focal point f2 and diffuser D2 in the position where the donut shape is erased totally as shown in figure 1. A collimating lens L1 is put between two diffusers to collect maximum light after diffuser D1. After the second diffuser, the donut shape is erased totally and the light distribution becomes uniform. In an ideal case, only one collimating lens is enough to collimate the beam. However, this lens needs to have a very long effective focal length. The two collimating lenses L2 and L3 after the diffuser D2 are proposed to optimize the occupied space.

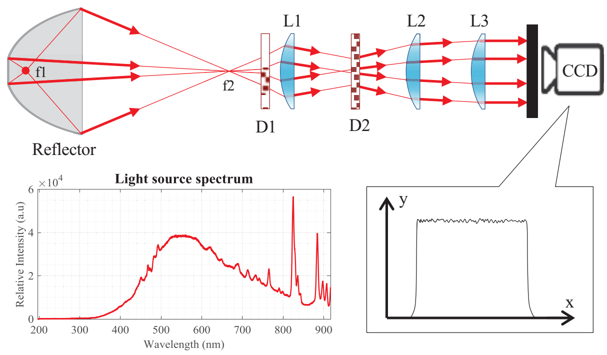

Fig. 1 Configuration to create the uniform beam from Xenon lamp

The lamp selection is the most important of this design concept. High-pressure xenon lamps are widely used in applications such as spectrophotometer, liquid chromatograph, microscope light source, solar simulation, etc. That lamps are filled with xenon gas that emits white light at a high color temperature, which is close to that of sunlight and broadband continuous spectrum from UV to IR (185 nm to 2000 nm). The discharge xenon arc lamp was chosen in this study because it has a small arc length, high intensity, high stability and long life. However, the disadvantages of the xenon lamp are the high price and require a special electronic assembly which is also quite expensive.

It is difficult to achieve a flat-topped beam profile from a point light source. The energy utilization rate of the system is very low. In order to obtain light as much as possible, choosing the reflector is the most important. In this study, the reflector selection follows the higher reflective proportion for the higher energy and the shorter focal length to optimize the system space. Depending on the light distribution of the xenon lamp was placed at the first focal point and optimized for the geometrical characteristics of the reflector, the chosen one can reflect 87% of the intensity and the focal length is 272 mm.

The diffuser is an optical component that uses a microscopic surface or bulk structure to reshape, control and homogenize the light distribution. By controlling precisely, the size, shape, location, distribution and scattering angle, an input beam can be produced the desired output pattern. The selected diffuser required a high transmission efficiency and enough scattering angle to erase the donut shape. In this study, we chose the holographic diffuser with high transmission efficiencies of over 92% at a broadband spectrum and the scattering angle is 25 degrees.

Depending on the type of application, the lenses are selected with different characteristics. In general, the collimating lenses are selected based on the diameter and effective focal length. The larger diameter lenses are applicable for more applications and users can easily reduce the beam size by blocking the unexpected area. The lenses with a shorter focal length will optimize the system space. In this study, we selected two lenses with the diameter is 50.8 mm and the effective focal length is 88.3 mm.

3. Results and Conclusion

Based on using double diffusers and collimating lenses, we designed a high uniform illumination system with a broadband spectrum from UV to IR. Evaluation with ISO 13694:2018, beam uniform is 76% with the divergence angle is 15 degrees. It has great prospects and is applicable for key industries such as semiconductors, inspection, spectrometer, etc.

However, the divergence angle is still large and the uniform beam can be higher. In future work, we will focus on optimizing the divergence angle and beam uniformity.

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